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BULLETIN
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL, 1938

GEOLOGIC OCCURRENCE OF OIL AND GAS IN MICHIGAN[1]

B. F. HAKE[2]
Saginaw, Michigan

ABSTRACT

The age of the oil- and gas-bearing rocks in Michigan ranges from Mississippian to Ordovician, and one gas occurrence is doubtfully in the Pennsylvanian. Gas is also locally present in the glacial drift where it has presumably accumulated from immediately underlying Paleozoic rocks. Oil is known to occur in eleven distinct horizons of which nine have proved productive, and gas occurs in nine separate horizons of which five are being actively exploited.

Deep wells have disclosed the general features of the stratigraphy of the state. The results of drilling indicate that in the deepest parts of the Michigan basin the oldest known sediments likely to contain oil and gas would be found at depths not exceeding 10,000 feet.

Examination of samples has shown the presence of several types of porosity, most of which are in some manner associated with dolomite. It is suggested that adequate knowledge of the manner in which dolomite has been formed would probably provide some valuable clues to the origin of petroleum.

INTRODUCTION

SCOPE OF PAPER

In this paper the writer attempts to formulate a preliminary statement and give a brief description of the geological conditions under which oil and gas occur in Michigan. The paper is a summary of observations by the writer during nearly 3 years of rather intensive study of well samples, but without the benefit of close acquaintance with the outcrop sections. The lithologic groupings made by the writer may not correspond exactly with the formations and groups into which the surface workers have subdivided the rocks exposed in outcrops around the margins of the basin. For a long time it will be

[1] Read before the Association at Pittsburgh, October 16, 1937. Manuscript received, December 1, 1937.

[2] District geologist, Gulf Refining Company.

impracticable to reconcile the rock units adopted by subsurface workers with those established by surface observers, for the subsurface worker becomes acquainted with many strata which are not known in outcrops and some formations described by surface workers can not be identified from well cuttings.

ACKNOWLEDGMENTS

The writer is indebted to the Gulf Refining Company for the opportunity to make these studies and permission to present the tentative results. In the work of examining samples he has been efficiently assisted by Jed B. Maebius and Mrs. Helen Cannon. A growing recognition of the value of samples among all the companies and individuals drilling for oil and gas in Michigan, and a willingness to accomodate on the part of most operators has made possible a more extensive and detailed collection of subsurface data during the last 3 years than during any similar period in the past.

STRATIGRAPHY

The stratigraphy of the state is not fully understood because the stratified rocks are concealed nearly everywhere by glacial drift, and because operators have failed to preserve samples from many of the wells drilled. Moreover, no complete study has ever been made of all the samples which have been saved. In Michigan very few cores have been taken and in the samples recovered fossil evidence is nearly destroyed. Subsurface correlations are therefore based almost entirely on lithologic similarities and must remain tentative until sufficient information has accumulated to permit an understanding of the lateral variations in lithology and thickness of the individual formations.

All rock descriptions here presented are results of sample examination performed or verified by the writer, but in preparing the figures it has been necessary to generalize the descriptions in order to form units capable of portrayal on a satisfactory scale. On this account rock units are indicated according to their dominant characteristics. For example, many subdivisions shown as shale include minor limestones or thin sands; units shown as anhydrite ordinarily contain considerable quantities of dolomite; and sediments indicated as dolomite include highly dolomitic limestones.

PENNSYLVANIAN ROCKS

Saginaw formation.—The Saginaw formation includes the youngest rocks which have a very widespread occurrence in Michigan. It is composed of gray, black, and green shales and white sandstones. It

also contains local coal seams and here and there limestone lentils. Relatively few complete sets of samples from this formation are avail-

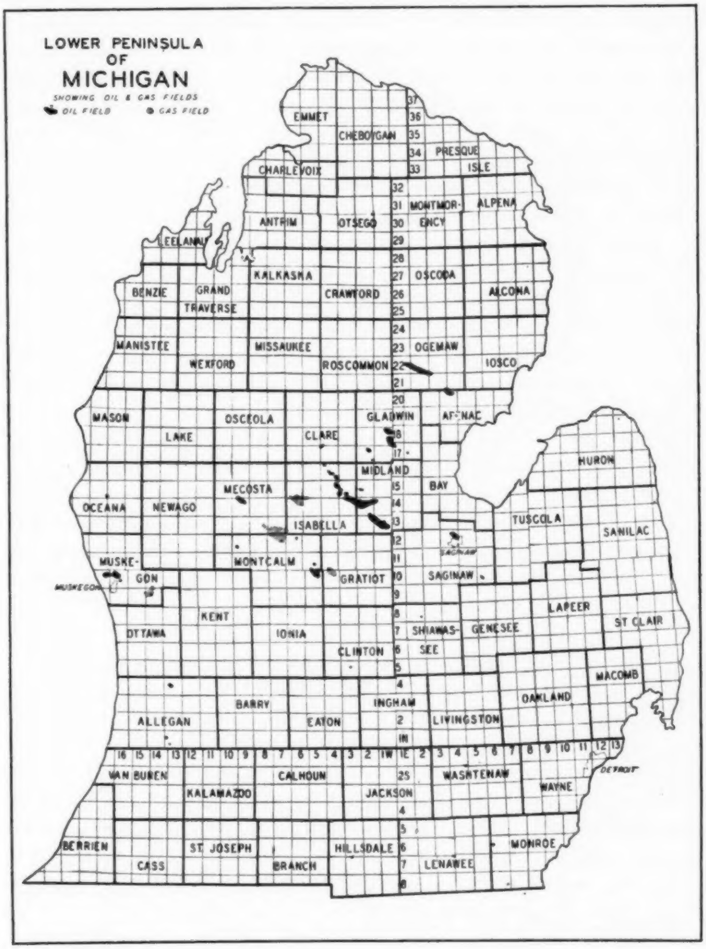

FIG. 1.—Index map of Lower Peninsula of Michigan showing oil and gas fields and county and township boundaries.

able, but from them it appears that heterogeneity is its outstanding characteristic.

MISSISSIPPIAN ROCKS

Bayport formation.—Below the Saginaw formation there is a series of sandstones, sandy limestones, limestones, and dolomites which is very persistent and widely distributed. This series lies on the eroded edges of all members of the Michigan and Marshall formations, thus making one of the most distinctly unconformable contacts which the writer has been able to detect in the Paleozoic sediments of the state. The sequence of rocks within the lithologic unit seems to be very irregular. Limestones closely resembling those exposed in the Bayport Quarry of Huron County appear in nearly every section of it, but seem to be lentils with erratic vertical distribution.

This formation is recognized in nearly all well logs and identified as Parma (basal Pennsylvanian) by most geologists, but in the writer's opinion it includes all the Bayport described by Lane[3] and earlier workers, and by them considered as Upper Mississippian. It may include, or may have nothing in common with, the Parma of the type locality in Jackson County, which is considered to be the basal member of the Pennsylvanian section in Michigan.[4]

Michigan and Marshall formations.—The Michigan formation includes a series of shales with many extensive beds of gypsum and numerous lentils of limestone, dolomite, and sandstone. The sand is most plentiful in the lower part of the formation. According to generally accepted terminology, the Marshall formation which underlies the Michigan includes a massive rather well sorted sandstone, ordinarily white but containing some red material, and an underlying series of fine, ill-sorted, red sandstones and shales.

The conception that the Michigan formation is unconformable on the Marshall[5] has received widespread acceptance but examination of samples from several scores of wells which penetrated these formations has convinced the writer that the contact between the Marshall and the overlying Michigan formation is gradational and that the top of the massive Marshall sandstone is not a single stratigraphic horizon, although for convenience in subsurface calculations over small areas it may be treated as such.

Coldwater formation.—The Coldwater formation of Mississippian age is generally a monotonous series of gray shales, many of them silty, generally concretionary and interbedded with thin sandstones.

[3] A. C. Lane, "Geologic Report on Huron County, Michigan," *Michigan Geol. Survey*, Vol. 7, Pt. 2 (1900), pp. 103–13.

[4] W. A. Kelly, "Pennsylvanian System in Michigan," *Michigan Geol. Survey Occas. Papers, Geol. Michigan, Pub. 40*, Geol. Ser. 34 (1936), p. 160.

[5] R. B. Newcombe, "Oil and Gas Fields in Michigan," *Michigan Geol. Survey Pub. 38*, Geol. Ser. 32 (1933), p. 55.

In most of the state these sands are fine-grained and gray, but in eastern Michigan many of them are red and pebbly.

Sunbury formation.—The Sunbury formation is a remarkably uniform bed of black shale with an average thickness of approximately 30 feet which is lithologically indistinguishable from the Antrim. It is regarded as a "finger" from the top of the Antrim, as in the central part of the state there is an area where both seem to be present with no apparent break between them.

Berea and Bedford formations.—In the lower part of the Mississippian section between the black shales which compose the Sunbury and the Antrim formations there is, in the eastern part of the state, a series of gray sands and shales which is subdivided into Berea and Bedford formations. The Berea formation consists of interbedded light gray sandstone and shale. The sands are generally fine-grained and tightly cemented with dolomite. The Bedford formation is composed of light-colored shales and silts and is not known to contain any members which would appear likely to have generated the oil and gas which is found in many localities in the Berea.

In the western part of the state there is a thick series of greenish gray shales, sandstones, and dolomites which rest on the Antrim, and for which the name Ellsworth[6] has been proposed. The Ellsworth formation is probably not exactly equivalent to either the Berea or Bedford, although part of it may be contemporaneous with either or both of those formations.

DEVONIAN ROCKS

Antrim formation.—The Antrim formation, considered to be partly of Mississippian and partly of Devonian age, is dense shale, dark brown to jet black in color, plentifully sprinkled with fossil spore cases and heavily charged with organic matter.

Traverse group.—The Traverse of Michigan has been subdivided into several formations[7] some of which may be recognized in well samples.[8] In the western part of the state it consists almost entirely of limestones and dolomites (Figs. 3–5) with some anhydrite. In the central part of the state the dolomites and anhydrites are present in much smaller quantity or entirely lacking. Here most of the group is

[6] R. B. Newcombe, *op. cit.*, p. 49.

[7] Erwin R. Pohl, "The Middle Devonian Traverse Group of Rocks in Michigan, A Summary of Existing Knowledge," *Proc. U. S. Nat. Museum*, Vol. 76, Art. 14 (1929), pp. 1–34.

[8] B. F. Hake and Jed B. Maebius, "Lithology of the Traverse Group of Central Michigan," read before *Michigan Acad. Sci.* (March, 1937).

made up of limestones which are apparently of reef origin. Toward the east it becomes increasingly shaly as far as it is known.

Dundee formation.—What is generally called Dundee is a buff-to-brown limestone which is composed for the most part of finely comminuted fragments of crinoids, hydroids, and calcareous algae, but also includes some dolomitic limestones and dolomites. It thickens within a short distance eastward from the center of the state, and its greatest known thickness (Fig. 4) is nearly 400 feet.

Ehlers and Radabaugh[9] now propose to separate the upper 100 feet of what has been called Dundee in northern Michigan and to call it the Rogers City formation. Subdivision of the remaining lower part may also finally be desirable.

According to currently accepted definitions the contact of the Dundee and Detroit River is at the place where the rocks above are predominantly limestones and those below entirely composed of dolomite or anhydrite. In many places, however, there is no anhydrite at the contact between limestone of the Dundee type and massive dolomite below it. Under such circumstances the accepted definitions fail to define, because in some localities pure holocrystalline dolomite of considerable thickness is both overlain and underlain by limestones which are definitely Dundee in type, and possibly in age.

Detroit River formation.—The Detroit River formation throughout most of the state consists of interbedded dolomite and anhydrite. In the northern part of the state (Fig. 2) it contains important beds of salt. One of the wells in the north-central part of the state (Fig. 1) reported nearly 500 feet of salt. Unfortunately, samples from this part of the hole were not saved, so it is impossible to learn just how much of this thickness was actually salt.

Sylvania formation.—The Sylvania formation in its surface exposures consists of dolomite and dolomitic limestones enclosing grains, lentils, and beds of well rounded quartz sand. Samples from some wells show that chert is associated with sandy dolomites in the part of the column which should represent the Sylvania formation. In localities where the sand is missing there is generally some cherty limestone between the parts of the section which appear to be Detroit River and Bass Island. When either sand or chert occurs in the right part of the column subsurface workers generally correlate such occurrences tentatively with the Sylvania, although it is by no means demonstrated that all such occurrences are actually synchronous or parts of one continuous rock unit.

[9] G. M. Ehlers and R. E. Radabaugh, "The Rogers City Limestone, a New Middle Devonian Formation in Michigan," unpublished manuscript, read before *Michigan Acad. Sci.* (March, 1937).

PRE-DEVONIAN ROCKS

Relatively few wells have penetrated the pre-Devonian formations in Michigan and none has done so in the deeper parts of the basin. These rocks do not now yield important commercial oil or gas in Michigan and they are not being intensively prospected. For all these reasons the writer has given them comparatively little attention and is therefore not qualified to describe them adequately.

Bass Island formation.—The Bass Island is composed of dolomite and anhydrite, the former predominating. If it were not for the cherty and sandy limestones and dolomites which indicate the presence of the Sylvania it would be difficult, or perhaps impossible, for the subsurface worker to separate the Bass Island from the Detroit River.

Salina formation.—The Salina formation contains dolomites and anhydrites very similar to those of the overlying formations but differs from them by also including important beds of red, green, and gray shales, and where typically developed (Figs. 2 and 5) several hundred feet of salt. In some localities the salt is missing but shales, dolomites, and anhydrites are present where the Salina should be and are accepted as representative of that formation. No very definite criteria have been developed for the identification of the upper or lower limits of the Salina.

In spite of the agreement among surface workers that the Sylvania is unconformable on the underlying Bass Island the writer suspects that the Salina, Bass Island, Sylvania, and Detroit River together are the record of one period of evaporite deposition and that unconformities present in this section are of local extent and probably confined to the marginal parts of the Michigan basin.

Older Silurian and Ordovician formations.—So far as the writer's acquaintance with them extends, the rocks which lie below the Salina and above the St. Peter sand seem to be fairly uniform in their general characteristics over most of the state. A series of light-colored dolomites and limestones presumably representing Middle Silurian (Niagaran) time is almost everywhere present beneath the Salina. Below these, there are thick beds of green or red calcareous shales and generally an underlying series of limestone or dolomite which together seem to be a record of the Lower Silurian (Medinan or Alexandrian). Upper Ordovician time is consistently represented by a series of shales, commonly red or green at the top, nearly everywhere gray in the middle and almost black at the base. These rest on a brown highly fossiliferous locally dolomitic limestone which is called "Trenton" wherever recognized but which may include representatives of all the Middle Ordovician formations. By many deep wells the "Tren-

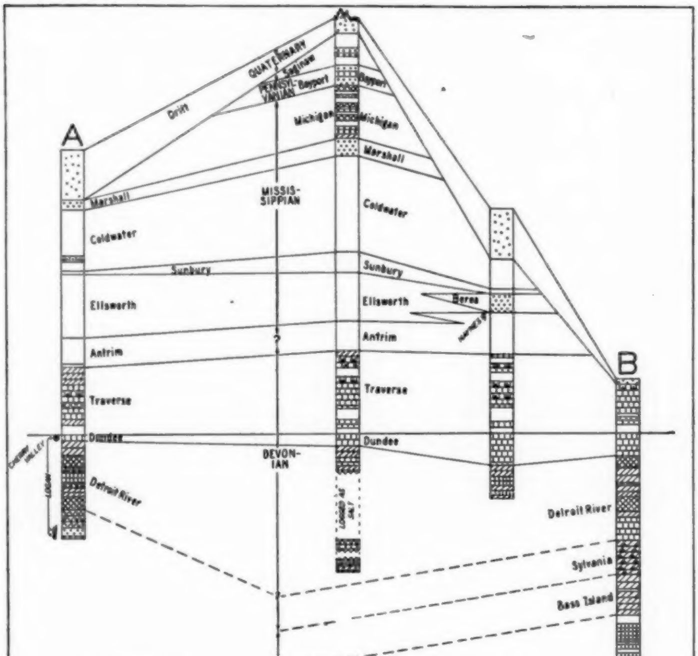

FIG. 2.—Columnar section of rocks revealed by drilling in northern Michigan.

ton" is shown to be resting on pure, well rounded sand, presumably St. Peter, but some show that it rests on other rocks which are probably older than the St. Peter.

OIL AND GAS OCCURRENCES

GENERAL STATEMENT

Oil and gas have not yet been produced in the Upper Peninsula of Michigan, so that part of the state is not considered in this paper. Oil occurs in the Lower Peninsula of Michigan in eleven distinct horizons, and production has been developed from at least nine of these. The producing zones range in age from Devonian to Ordovician. Oil is found most commonly in porous dolomites, but also occurs in limestones and sandstones. From the meager information now available it seems that the oils found associated with pure dolomites have a higher sulphur content than those found in limestones and sandstones. There does not appear to be any systematic relationship between the characteristics of the oils and the ages of the rocks in which they are found.

Although natural gas occurs in some quantity with all oil produced, gas so recovered does not constitute a very large part of the commercial gas production of the state. In most fields there is insufficient gas for lease operation before the oil production declines below the economic limit. In addition to that which occurs with oil, natural gas is encountered at nine geologic horizons which range in age from Upper Mississippian (or possibly Pennsylvanian) to Middle Silurian. Only five horizons are being exploited at present. Most of the commercial gas so far developed in Michigan is found in sands, but in at least one place it occurs in a dolomite.

OIL AND GAS IN NORTHERN MICHIGAN

The northern part of the Lower Peninsula of Michigan has been but little explored by drilling. Figure 2 shows parts of the geologic column in four localities in the northern part of the peninsula.

Antrim formation.—The Antrim shale yields gas in many localities in Michigan, but has not yet been exploited except in a small way for domestic use from privately owned wells. So far as is known this is a true shale gas, not concentrated in sandy or calcareous lentils.

In Manistee and Mason counties gas was encountered by wells at depths between 400 and 600 feet. This gas was reported to be near the base of the glacial drift, and to be under pressures approximating 200 pounds per square inch. As the Antrim formation lies beneath

the drift in this district, the gas presumably found its way into the drift from the Antrim shales.

In Montmorency County there are numerous vents where gas reaches the surface in small quantities and this gas has also been supposed to have come from the Antrim shales. In Haynes Township (T. 27 N., R. 9 E.), Alcona County, several wells were drilled in an attempt to produce commercial gas from the Antrim. In some of these the quantities of gas encountered were insignificant. In others, shooting with nitro-glycerine, which was performed for the purpose of increasing the flow of gas, damaged the wells to such an extent that they could not be satisfactorily tested. These operations have been suspended.

Dundee formation.—Small quantities of oil and gas in the Dundee have been reported in several wells in this district, but few of these reports could be verified. One well in Logan Township (T. 17 N., R. 15 W.), Mason County, and one in Cherry Valley Township (T. 18 N., R. 12 W.), Lake County, found encouraging amounts of oil but both were abandoned without developing commercial production. In both of these cases the oil occurred in dolomitic phases of the Dundee, or in the Detroit River formation.

Sylvania formation.—Small flows of gas and small amounts of oil were encountered in some wells drilled in Logan Township (T. 17 N., R. 15 W.) of Mason County in a series of sandstones and sandy dolomites which are tentatively correlated with the Sylvania. Several wells have been drilled in this district but no commercial production has been developed. It would seem that when this series is tested under proper structural conditions, and where it is not too tightly cemented, it might yield profitable quantities of oil and gas.

Pre-Devonian formations.—The pre-Devonian formations have not been extensively explored in the northern part of the peninsula, and no oil showings have been reported from them. The general nature of these rocks is shown by one log in Figure 2. The well represented by this section was drilled through the greatest thickness of Salina formation which has so far been encountered in the state, about 2,050 feet of strata of which 1,180 feet was fairly pure salt.

NORTH-CENTRAL MICHIGAN

Most of the commercial oil and gas production so far developed in Michigan occurs in a zone of fields extending across the central part of the Lower Peninsula from Muskegon County on the southwest to Ogemaw County on the northeast (Fig. 1). Most of the gas produced in this region is obtained from sands of Mississippian age,

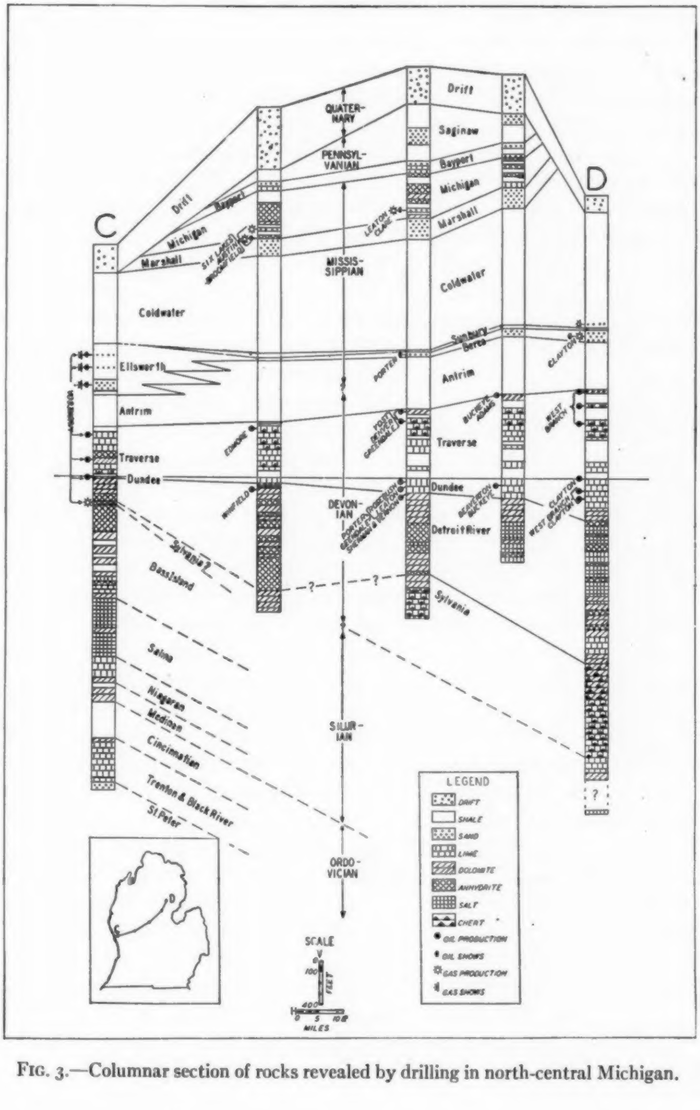

FIG. 3.—Columnar section of rocks revealed by drilling in north-central Michigan.

and most of the oil is produced from Devonian limestones and dolomites.

Michigan and Marshall formations.—These formations underlie most of the area of the peninsula, and contain its most important known resources of dry natural gas. It is widely accepted that the Michigan formation is unconformable on the Marshall and that the gas occurs in a sand or sands belonging to the Michigan formation, and usually spoken of as the "Michigan stray." This idea was accepted by Rawlings and Schellhardt,[10] but the writer takes an opposing stand. It is believed that the gas occurs both in the top of the massive sandstone of the Marshall formation and in separate sands at various distances above the base of the Michigan formation. The distribution of the gas suggests that it is confined to the vicinity of some unidentified source beds among the Michigan shales and limestones, from which it has migrated into sands of the Marshall or the Michigan and accumulated where traps were produced by the combined effects of structural and sedimentary processes.

The gas in the Clare (T. 17 N., R. 4 W.) and Leaton (T. 15 N., R. 3 W.) fields seems to be in a sand which should be included in the Michigan. There is reason to suspect that the principal gas horizon of the Six Lakes field (T. 13 N., R. 7 W.) is stratigraphically not very different from that of the Clare field, but in Six Lakes most of the gas is in a sand that can not positively be separated from the massive sandstone which is Marshall by general agreement.

It seems probable that the upper (massive sandstone) member of the Marshall is a littoral facies of a part of the Michigan formation and that the "Michigan strays," of which there are several, are "fingers" from the top of the Marshall or isolated sand lentils contemporaneous with parts of the Marshall. Hard,[11] working independently, arrived at substantially the foregoing conclusions and previous workers probably would have done likewise had they not been misled by drillers' logs and hampered by lack of adequate sample collections.

Berea formation.—Gas wells of considerable size are completed in the Berea in the Clayton field (T. 20 N., R. 4 E.) in Arenac County. Small amounts of oil have been produced from the Berea by a well in northeastern Midland County (T. 15 N., R. 2 E.) but it has never been rated as commercial. Many wells in the Porter field (T. 13 N., R. 1 W.) of southwestern Midland County showed oil when drilled

[10] E. L. Rawlins and M. A. Schellhardt, "Extent and Availability of Natural Gas Reserves in Michigan 'Stray' Sandstone Horizon of Central Michigan," *U. S. Bur. Mines R. I. 3313* (1936).

[11] E. W. Hard, "The Stray Sands of the Michigan Series in Central Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 2 (February, 1938), pp. 129–74.

through the Berea but no commercial production has been developed.

The fact that the Berea-Bedford series is enclosed between the underlying Antrim shale, known to be gas-bearing, and the overlying Sunbury shale, exactly like the Antrim, encourages acceptance of the hypothesis that the oil and gas found in the Berea were derived from one or both of these black shales. Gas found by a few wells in a sand near the base of the Coldwater shale, only a little way above the Sunbury, lends additional apparent support to this idea. However, the fact that oil and gas are not ordinarily found either at the top of the Berea or the base of the Bedford suggests that perhaps these substances were generated in some of the sediments included in the Berea or Bedford.

Ellsworth formation.—The Ellsworth formation in the Muskegon district (*C*, Fig. 2) is a series of green and gray shales with interbedded sands and dolomites. Numerous showings of oil and gas are reported in this part of the column by wells drilled in and near the Muskegon field, but so far as known none of these was ever developed commercially. It is nevertheless possible that some of them could have been so developed, as small gas wells were of little interest to oil prospectors at the time when the Muskegon district was being prospected.

The logs of many wells drilled east of Muskegon show that rocks similar to those of the Ellsworth are interbedded with shales of the Antrim type, and this condition is regarded as evidence of contemporaneous deposition of the upper part of the Antrim and the lower part of the Ellsworth. Here also is a suggestion that gas and possibly oil from the Antrim formation may have found its way from the Antrim into overlying or contemporaneous rocks.

Traverse group.—Oil has been found in the Traverse group in almost every part of the state where much drilling has been done, but so far most of the accumulations discovered have not been sufficiently prolific to be really profitable. A few wells have produced at a profitable rate for a few months. Traverse production is generally regarded as only incidental to the completion of wells in the underlying Dundee.

At the top of the Traverse section in central and northeastern Michigan there is a dolomitic limestone about 30 feet thick which has produced satisfactorily in a few areas. Although fairly regular in thickness and appearance this member is extremely variable in porosity, and some of the best wells which produce from it are situated on the flanks of structures. An accumulation of oil in this member is now being developed in Adams Township (T. 19 N., R. 3 E.) of Arenac County. In the Clayton field (T. 20 N., R. 4 E.) it is a horizon of flowing salt water but has not yet been found to contain oil. Oil from

this dolomitic member in the West Branch field (T. 22 N., R. 2 E.) is black, has a gravity of 34° A.P.I., and a moderately high sulphur content.

In West Branch two lower porous limestones of the Traverse produce in certain wells and fail to yield oil in others. The irregular porosity of these limestones seems to have caused localized oil accumulations, both on and near anticlinal axes.

In the Edmore field (T. 12 N., R. 6 W.) of Montcalm County, only one oil zone has been discovered. This zone is found in a cherty limestone near the top of the formation but stratigraphically lower than the dolomitic zone previously described. A horizon approximately equivalent to the productive zone of the Edmore field and yielding a similar grade of oil is productive in some wells in the Denver (T. 15 N., R. 2 W.) and Yost (T. 14 N., R. 3 W.) pools in Midland County.

In the western part of the state there are two Traverse oil horizons: one near the top of the formation, and another near the middle, just below the most prominent anhydrite zone. In each of these the oil is found in a dolomitic limestone. Although the upper "pay" of the Muskegon field (T. 10 N., R. 16 W.) seems closely equivalent stratigraphically to the productive zone of the Edmore field, the oils from these two areas are very different. The Edmore oil is green, has a gravity approximating 43° A.P.I., and has a low sulphur content. The Muskegon oil is black, has a gravity of about 37° A.P.I., and a high sulphur content.

Dundee formation.—The Dundee formation is the most important oil-producing horizon so far developed in Michigan and most of the current prospecting is designed primarily to test this formation. The wells are abandoned if they encounter water in it. Oil is produced from several different horizons within the Dundee.

In the Clayton field (T. 20 N., R. 4 W.) a zone within the upper 25 feet of the Dundee yields showings of oil in practically every well drilled, and in two small areas produces prolifically. Several of the wells completed in this zone have flowed more than 1,000 barrels per day for several months. Although this same zone occurs in the West Branch field (T. 22 N., R. 2 E.) no large producing wells have yet been reported from it. The oil from this zone in the Clayton field is black, has a gravity of 34° A.P.I., and a very high sulphur content.

In both West Branch and Clayton the most dependable "pays" range from 100 to 200 feet below the top of the Dundee, but within this zone there seem to be several lenticular oil-bearing strata. Wells completed in this zone vary from small to moderate in size, but their

daily rates of production decline slowly and there seems to be good reason to anticipate a profitable total recovery from the average well completed in this zone. The oil produced from this part of the Dundee formation is not very different from that recovered from the higher zone.

In the Buckeye (T. 18 N., R. 1 W.) and Beaverton (T. 17 N., R. 2. W.) fields of Gladwin County oil is found in the Dundee 50–60 feet below the top of the formation, near the contact of an upper member of dense brown limestone and a lower member of buff fossiliferous and slightly dolomitic limestone. This oil is green, has a moderate sulphur content, and a gravity of approximately 40° A.P.I. It seems that the horizon of the Gladwin County production is stratigraphically close to that of the lower oil zone of the West Branch and Clayton fields. The reason for the marked difference between the oils of the two districts is not apparent.

In the Porter (T. 13 N., R. 1 W.) and Greendale (T. 14 N., R. 2 W.) fields in Midland County oil is found in the central and upper parts of the Dundee, and the available information indicates that most of the production comes from a horizon stratigraphically close to the one that is productive in Gladwin County. The oil in these fields is green, has a gravity of about 41° A.P.I., and a low sulphur content.

In the Vernon field (T. 15 N., R. 4 W.) the oil is found in a massive dolomite only a few feet below the base of the Traverse formation. It is a generally accepted opinion that this oil is really in the top of the Detroit River formation but that idea is questionable because wells close to this field penetrated considerable thicknesses of Dundee. The oil from Vernon is similar in color and sulphur content to that of other near-by fields, but is higher in gravity, approximately 44° A.P.I.

Throughout the west-central part of the state most wells find comparatively small thicknesses of Dundee, and in many places the presence of that formation can not be definitely demonstrated because the rocks immediately beneath the Traverse formation are almost pure dolomite. In the Muskegon field (T. 10 N., R. 16 W.) logs indicate that the Dundee ranges from 10 to 30 feet in thickness and that the oil occurs near the middle of this interval. The writer has never seen a sample of the Dundee formation from the Muskegon field, but samples from wildcat wells in the vicinity show that the characteristics of the Dundee in that district are not notably different from those displayed by it in other parts of the state. An analysis[12]

[12] E. L. Garton, "Analyses of Crude Oils from some fields of Michigan," *U. S. Bur. Mines R. I. 3346* (1937), p. 19.

of oil from the Dundee of the Muskegon field shows it to have a brownish green color, a high sulphur content, and a gravity of 36° A.P.I.

Detroit River formation.—Showings of oil are reported from the Detroit River formation in logs of almost all wells which have penetrated it to considerable depths, but the only oil which certainly is produced from it comes from two small wells in Winfield Township (T. 12 N., R. 9 W.) of Montcalm County. These wells produce from a porous brown dolomite below the highest anhydrite zone and 60 feet below what is accepted as the Dundee-Detroit River contact. The oil is light green, has a very high sulphur content, and a gravity of 43° A.P.I.

Oil in the Sherman field (T. 15 N., R. 6 W.) is generally believed to come from the Detroit River, as the productive zone is in massive dolomite and no Dundee has been identified within the limits of the field. However, there is no positive way to identify the dolomite in which the oil is found as Detroit River, and it may be found to be a dolomitic phase of the Dundee, for wells located short distances beyond the limits of the field have been drilled through considerable thicknesses of typical Dundee limestone. A sample of oil taken directly from a well in the Sherman field had a gravity of nearly 48° A.P.I., was fairly high in sulphur, and a very light green in color.

Sylvania formation.—A thick series of sediments tentatively correlated with the Sylvania formation is found in the northeastern part of the state (*D*, Fig. 3), but no oil or gas has been found in them. In the Muskegon field (T. 10 N., R. 16 W.) the so-called Monroe gas zone is a sandy dolomite which may be found to be the local equivalent of the Sylvania.

Pre-Devonian formations.—Very few wells have penetrated rocks of Silurian or Ordovician age in the central part of the state, but no doubt those formations will be prospected when conditions warrant testing them as all are within reach of the drill. It is estimated that in the deepest part of the Michigan basin the St. Peter sandstone would be found at depths between 9,000 and 10,000 feet.

SOUTH-CENTRAL MICHIGAN

The geologic formations of Michigan immediately south of the center of the state are not very different from the formations farther north where oil prospecting has met with more success, but this part of the state merits separate discussion because there are some types of occurrences of oil and gas which have not been duplicated.

Bayport formation.—Several wells were drilled some years ago in

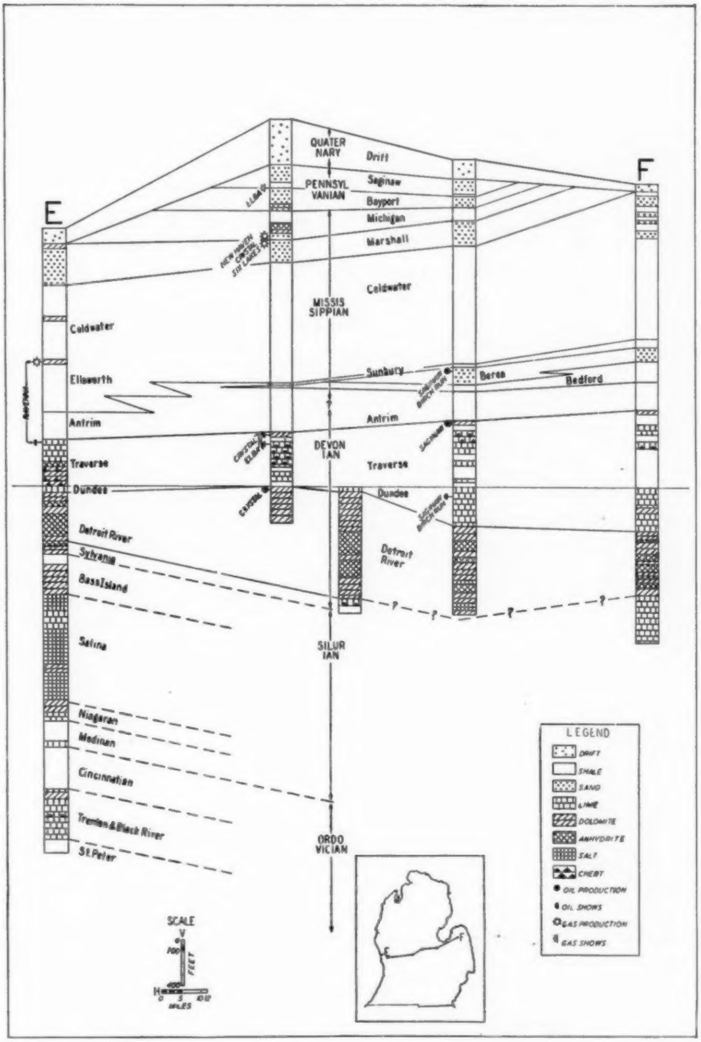

FIG. 4.—Columnar section of rocks revealed by drilling in south-central Michigan.

an attempt to develop commercial gas in Elba Township (T. 9 N., R. 1 W.) of Gratiot County from a sandstone called the Parma, but which may be proved to be Bayport. None of the wells was very large, and the pressure was not great, and the attempt has been abandoned. In a few other wells small showings of gas were reported from approximately the same horizon but no commercial production has been established.

Michigan and Marshall formations.—Gas in the New Haven (T. 10 N., R. 4 W.) and Crystal (T. 10 N., R. 5 W.) fields is found both in the Marshall sandstone and in higher sand lentils interbedded with the gypsiferous shales of the Michigan formation. Important showings of gas at these horizons outside the present area of commercial development indicate that drilling has not yet found the limits of the territory within which these formations contain commercial gas accumulations.

Ellsworth formation.—A sandy dolomite which produces gas in the Ravenna field (T. 9 N., R. 14 W.) of Muskegon County is commonly spoken of as Berea because it occupies a place in the geologic column somewhat similar to that of the Berea, and because about 60 feet above it there is a bed very similar to a red fossiliferous dolomitic limestone which generally is found not far above the Berea in eastern Michigan.

The designation of this gas horizon as Berea may be proved erroneous. The Sunbury has not been identified above it, neither has it been traced into, nor proved to be contemporaneous with, the Berea. Unless a correlation can be definitely established with the Berea it seems desirable to recognize that this gas-producing stratum is part of the Ellsworth.

Berea formation.—Important, though not very profitable, amounts of oil have been produced from the Berea sandstone in the Saginaw (T. 12 N., R. 4 E.) and Birch Run (T. 10 N., R. 6 E.) fields of Saginaw County. The Berea oil is green, has a moderate sulphur content, and a gravity of about 43° A.P.I. It has a larger gasoline content than have most of the Devonian oils of the state. In these fields only a small fraction of the thickness of the Berea sandstone is oil saturated and the pay sands are fine and apparently of low permeability. As the oil bodies do not seem entirely symmetrical with the structure, it seems that differential porosity has probably been an important factor in localizing Berea oil accumulations.

Traverse group.—In this part of the state oil is found both in the uppermost dolomitic member of the Traverse and in the upper part of the cherty limestones which compose most of the group. In the Crystal

field (T. 10 N., R. 5 W.) of Montcalm County oil was found in both of these horizons and a few wells produced from the Traverse for short periods. It seems certain that considerably more oil could have been recovered from this field had the wells been completed in a way which would have permitted production from the Traverse.

In the Saginaw field (T. 12 N., R. 4 E.) a few really profitable wells were completed in the higher of these oil zones, which was then known as "the Saginaw sand." Oil from this zone has not produced uniformly throughout the field and most of the wells of the field were not drilled deep enough to test it.

Dundee formation.—The Dundee attains its maximum known thickness in Huron County, and from Saginaw westward it thins within a short distance and is represented by less than 50 feet of limestone throughout extensive areas in southwestern Michigan. No commercial production has been developed from the Dundee in Michigan south of the line of section *EF* (Fig. 4).

Detroit River formation.—Although the producing horizon of the Crystal field (T. 10 N., R. 5 W.) is sometimes referred to as Dundee, it is probably in the Detroit River formation as the productive zone is in massive dolomite and wells which have been drilled below the oil horizon encountered nothing but dolomite and anhydrite. The oil from the Crystal field is green, has a gravity of 43° A.P.I., and a fairly high sulphur content.

About 6 miles southwest of the Crystal field one well is producing small amounts of oil under conditions similar to those at Crystal. Many other wells were drilled in the vicinity but failed to find oil.

Pre-Devonian formations.—Only a few wells in this part of the state have been drilled very far below the Dundee and there has been no production from any of these deep tests. Nothing is known about the oil possibilities of the Silurian and Ordovician rocks in the central part of the state for no wells there have been drilled below the Sylvania. In the shallower marginal parts of the basin most of the wells which did penetrate pre-Devonian rocks were drilled where little or nothing was known about local structure or were located on the edges of productive fields. Consequently none was a significant test of the oil possibilities of these older sediments.

SOUTHERN MICHIGAN

Antrim formation.—The youngest formation which produces oil or gas in southern Michigan is the Antrim. In Southfield Township (T. 1 N., R. 10 E.) of Oakland County and in Wayne and Macomb counties, where the Antrim shale is close below the base of the drift,

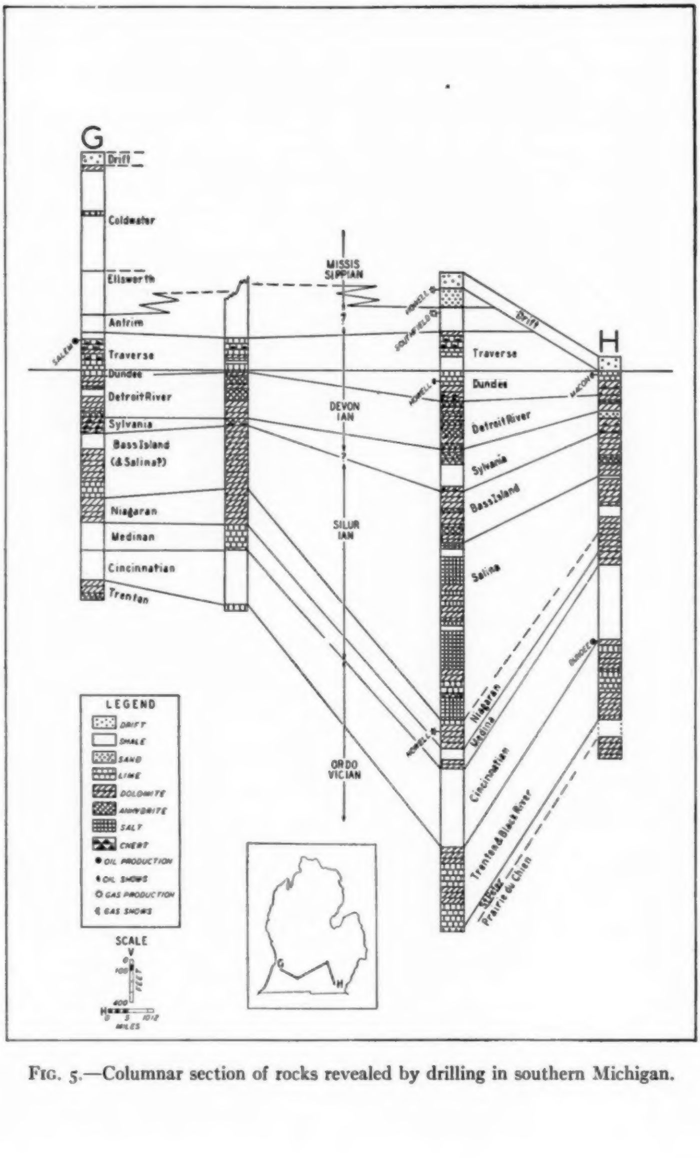

FIG. 5.—Columnar section of rocks revealed by drilling in southern Michigan.

many individuals have completed wells in the Antrim which produce gas for domestic purposes. Some of these declined rapidly and were abandoned, but others are reported to be still producing many years after completion.

Traverse group.—In southwestern Michigan showings of oil have been encountered in the Traverse in many widely separated localities, and some of the wells produced small quantities of oil for short periods. The first commercial production was discovered in 1937 in the Salem (T. 4 N., R. 13 W.) field, Allegan County, where about 20 wells are now producing. The oil in this district is found near the top of the massive cherty limestone of the Traverse, a horizon approximately equivalent to the first Traverse "pay" in the Muskegon field. The possibility of deeper producing zones in the Traverse has not yet been tested in the Salem field.

Dundee and Detroit River formations.—The Dundee and Detroit River in this part of the state display the same general characteristics as they do where they produce oil. They yield showings of oil and gas in many localities, and there is no apparent reason why oil in commercial quantities should not occur in them, but so far none has been discovered. The Howell anticline in Livingston County presents a puzzling example of these conditions. It is a large anticline more than 30 miles long and with several hundred feet of structural relief. It plunges northwestward and is probably faulted on its southwestern flank. Enough drilling has been done to demonstrate at least two low domes on this anticline and each has been tested by several wells. Many of these wells found showings of oil and gas in the Dundee but none was actually produced.

Silurian rocks.—A small flow of gas encountered in Silurian dolomite in the deep test at Howell (T. 3 N., R. 4 E.) lends some support to the hope that oil or gas in really important quantities may be encountered in rocks of this age in Michigan.

Trenton formation.—The Trenton limestone (probably including older Ordovician formations) consists of several hundred feet of brown highly fossiliferous limestone and dolomitic limestone. Since this formation has yielded much oil in Ohio it is regarded as a potential source of oil in Michigan and several wells in southern Michigan have tested it. Thus far the attempts to produce oil from the Trenton have not been profitable, but small quantities have been obtained from it in Dundee Township (T. 6 S., R. 6 E.) of Monroe County. The oil from this pool is green, has a gravity of 42° A.P.I., and a moderate

sulphur content. This is the only truly paraffine-base oil which Garton[13] found in Michigan.

So far as observed the outstanding difference between the character of this formation where it shows oil and where it does not is that in the districts where it shows oil it is more dolomitic than where no oil is found in it. In fact, in the localities where it is least dolomitic it yields no fluids at all. The deep test at Howell (T. 3 N., R. 4 E.) was apparently located near the apex of a well developed dome in the Devonian formations but the Trenton was not porous.

RESERVOIR ROCKS

SANDSTONES

The sandstones in which oil and gas are known to have accumulated in Michigan are in the Bayport ("Parma"), Michigan, Marshall, Berea, and Sylvania formations. In the Michigan, Marshall, and Berea formations oil and gas have accumulated in sandstones which are less densely cemented than the adjacent parts of those formations. From the samples which have been seen it appears that the cap rocks which confine these accumulations are, as a rule, not shales but sandstones tightly cemented with lime, generally in the form of a dense dolomite. Although the gas-producing zone in the Ravenna field (T. 9 N., R. 14 W.) is sandy and is commonly called Berea, samples from it indicate that most of the porosity is due to voids between euhedral crystals of dolomite. The writer is not familiar with the rocks which contain the gas in the Bayport and Sylvania occurrences.

LIMESTONES AND DOLOMITES

Traverse group.—Porosity in the Traverse group seems to be of three classes, (1) voids between dolomite crystals, (2) openings within fossils and between fossil fragments, (3) openings associated with chert, which, when adequately studied, may be proved to belong to one or both of the preceding classes.

The uppermost productive horizon of the Traverse group is a pure granular dolomite associated with dense, gray, fossiliferous limestones. Porosity in this member seems to be uniformly confined to the granular dolomite, but the dolomite is not everywhere porous.

The lower fluid-bearing zones of the Traverse group occur in massive limestones which are believed to be composed to a large extent of coral-reef material. The more cherty members of this series are persistently porous and samples from the oil-producing zones ordinarily contain a considerable amount of dolomite. Porosity in these fluid

[13] E. L. Garton, *op. cit.*, p. 19.

zones seems to be both among the fossil fragments and among the dolomite crystals, but this matter has not been exhaustively studied. The fine-grained gray and black limestones which make up a considerable part of the Traverse group are not known to contain any effective porosity.

Dundee formation.—In general the Dundee is a dense, rather than a porous formation. When porosity occurs, it is most commonly in a highly fossiliferous rock and the voids seem to be either within or between the fossil fragments. Stylolites also appear to contain fluids in some localities. Dolomitic phases of the Dundee grade through all variations from a dense limestone, in which tiny rhombs of dolomite are sparsely scattered through a matrix of micro-crystalline calcite, to a pure holocrystalline dolomite, without any recognizable calcite or vestige of calcareous fossils. It seems a fair generalization to say that the porosity of this type of Dundee varies directly with the dolomite content of the rock.

An interesting type of porous rock which has been rarely observed in the Dundee contains many spherical vugs of microscopic size. In the best observed sample of this type of rock the isolated vugs appeared to be empty or may have contained water. The ones which were entrained, or were connected by cracks or solution channels, have acted as reservoir space for oil.

Detroit River formation.—All porosity observed in the rocks of the Detroit River formation is due to angular spaces between rhombohedral dolomite crystals. Observed voids vary in size from microscopic partings to cavities into which a finger could be inserted. The individual crystals of these porous dolomites are so imperfectly cemented that the rocks are ordinarily drilled up into small grains of uniform size, each grain consisting of from one to three or four individual crystals. Where open cavities occur in this dolomite they are commonly lined with perfectly formed crystals of glassy dolomite which are regarded as a second generation of dolomite crystals, formed after the voids were produced.

It is interesting and probably significant that most of the oil and gas occurrences in Michigan are in some degree closely associated with occurrences of dolomite, and that most of the pure dolomites of all ages in Michigan are brown, apparently because of an organic coating on the individual crystals. It seems highly probable that if geologists had more precise knowledge of the genetic history of dolomites they would be able to make an important advance toward an understanding of the origin of petroleum.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 4 (APRIL, 1938), PP. 416-430, 9 FIGS.

HISTORY OF DEVELOPMENT AND GEOLOGIC RELATIONSHIPS OF APPALACHIAN FIELDS[1]

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ABSTRACT

This paper presents, mainly graphically, the factors that limit the Appalachian oil and gas fields. On the west these are: (1) some of the formations that might contain oil or gas thin out or thin down; (2) especially, sandstones that serve as reservoirs are replaced by shales and limestones to leave no reservoir rocks. On the east the contributing factors are: (1) the rocks are mainly continental deposits and therefore non oil- and gas-bearing; (2) rock folding at the end of Carboniferous time distilled off any oil and gas that may have been present potentially east of the present fields or, for oil, below the present field; (3) the lines of equal pressure in the folding ran transverse to the lines of sedimentation so that in the southern Appalachians, the potentially favorable sediments at the east were caught in the belt of intense folding and their oil and gas content lost. Historically the paper emphasizes the close relation of early oil and gas discoveries to the salt industry.

This paper assumes that the members of the Association know all about the theoretical origin and distribution of oil and gas, but nothing about the occurrence of oil and gas in the Appalachian region.

Figure 1 shows the horizontal distribution of the known oil and gas fields of the Appalachian region which center about the geosyncline between the Appalachian uplift and the Cincinnati-Nashville arch. The oil occurs in a narrow belt and the gas in a somewhat broader belt, both of which gradually disappear toward the southwest. The oil fields increase in size and productiveness toward the northeast, the most productive field of all being at the extreme north end of the region on and near the boundary of Pennsylvania and New York.

In vertical distribution, the oil comes from sands (some of which are limestone) ranging in age from the middle Coal Measures down to the base of the Upper Canadian or Stones River, the most of the oil coming from rocks of Devonian age.

Figure 2 shows approximately the surface distribution of the oil sands according to age. Considerable oil has come from the Pennsylvanian of Ohio and West Virginia, especially from the Pottsville sandstones, though sandstones of Allegheny and Conemaugh age have supplied some oil. Oil of Pennsylvanian age is naturally confined to the center of the geosyncline, as away from that center all these rocks rise above drainage. The Mississippian oil sands cover the largest area

[1] Read before the mid-year meeting at Pittsburgh, October 14, 1937. Manuscript received, November 3, 1937.

[2] State geologist of Pennsylvania.

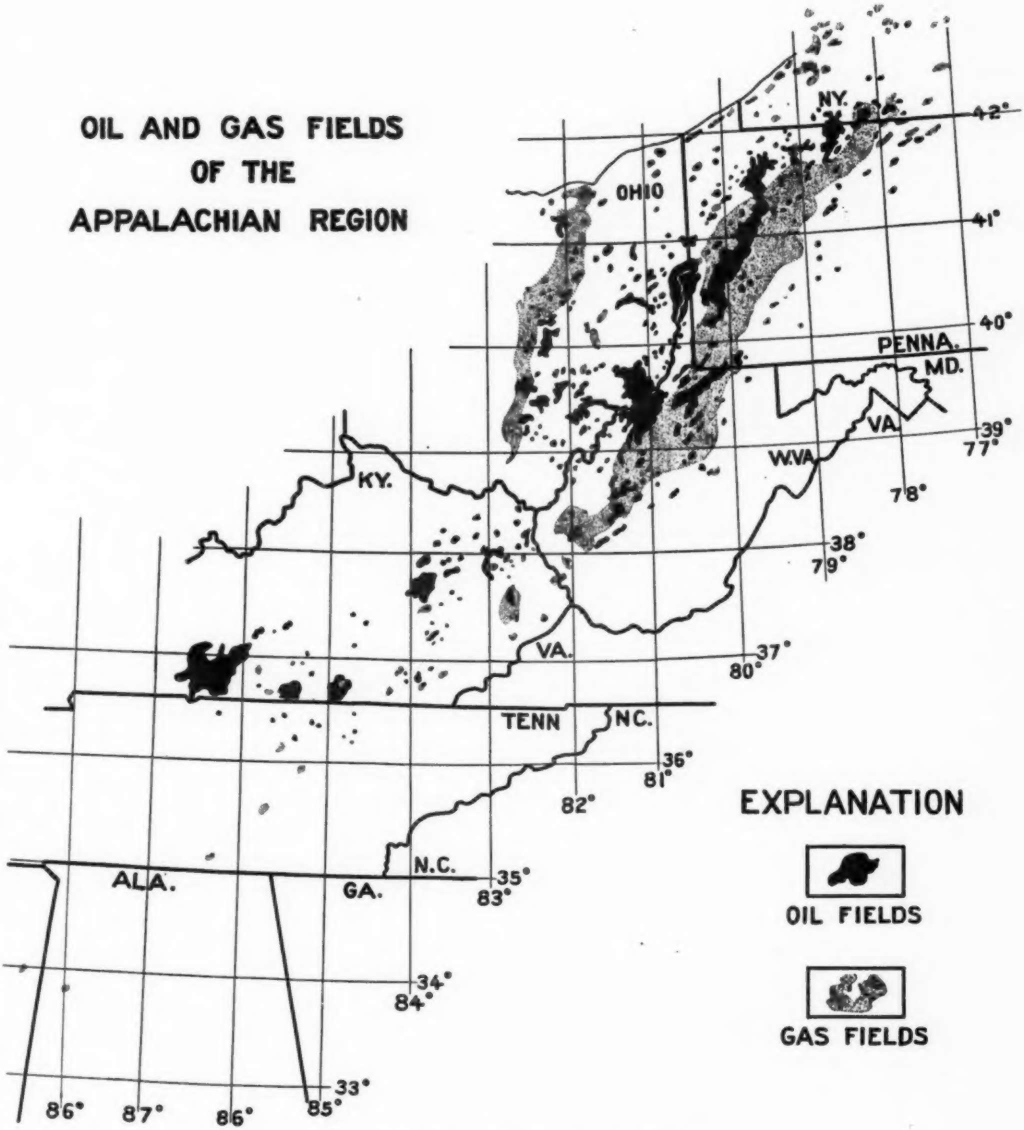

FIG. 1.—Oil and gas fields of Appalachian region.

but only locally have sands of this age been the principal producers. Much of the Mississippian production has come from the Berea sandstone at the very base of the system. This sandstone, ordinarily not more than 50 feet thick, has been traced, it is thought, from Lake Erie to the south end of Tennessee. It is only 1 or 2 inches thick in eastern Tennessee, and of course not there an oil producer.

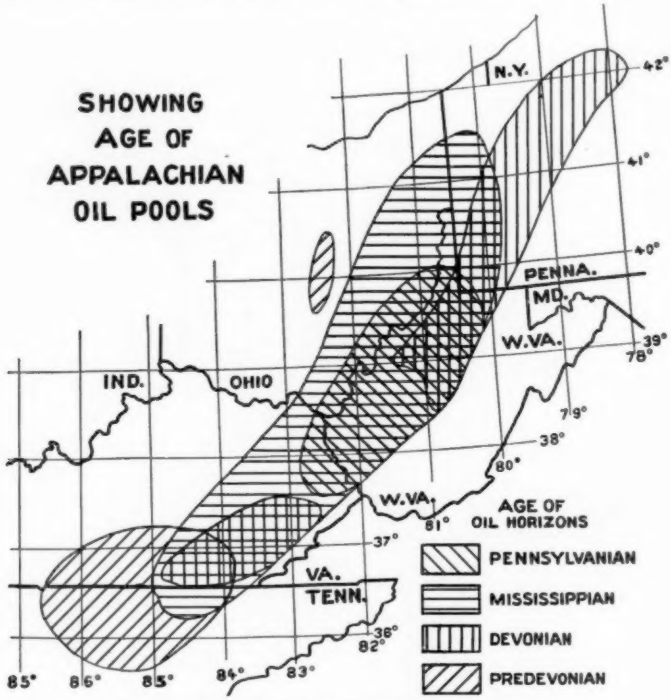

FIG. 2.—Appalachian distribution of oil sands by age.

Devonian oil is produced in two areas: one stretching from southern New York to the middle of West Virginia and including many sands; the other covering a small part of southeastern Kentucky, and including only one sand. A little oil and much gas have come from the Silurian, mostly from the basal sandstone, the Tuscarora of Pennsylvania, or the Clinton of Ohio. Sands of probable Niagaran age have produced oil in Kentucky and Tennessee. The Ordovician and upper Canadian have produced meager amounts of oil in Tennessee and Kentucky.

With these general facts before us, several questions naturally arise, possibly all summed up in one. Why are the oil and gas of the Appalachian region confined to the areas and to the strata in which they have been found?

Figure 3 presents broadly a picture of the occurrence of oil and gas in the vertical section of strata in the northern part of the field.

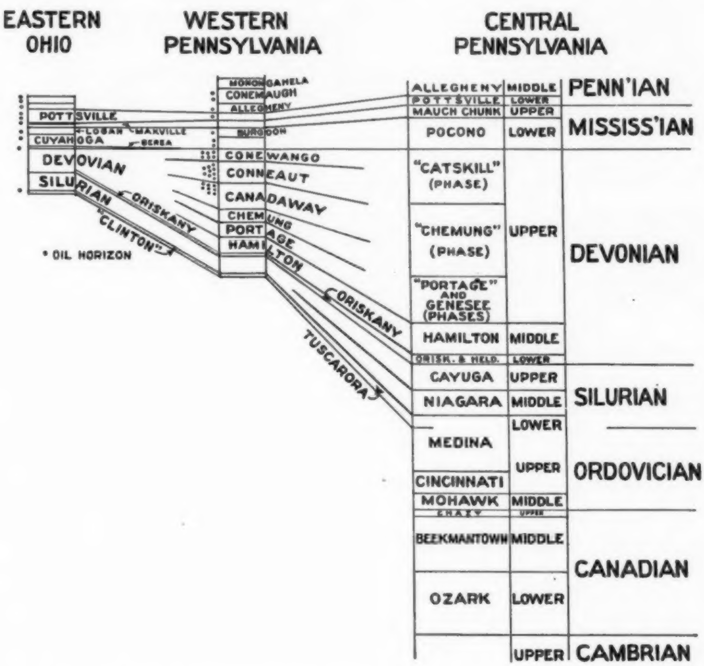

FIG. 3.—Chart showing vertical position of oil and gas in Pennsylvania and Ohio and thinning of rocks from east to west.

In this part of the field no oil or gas older than Silurian has been found.[3] Most of the oil has come from about the middle of the Upper Devonian and higher, though gas has come from the basal Devonian in New York, northern Pennsylvania, West Virginia, and Ohio, and gas and oil from the Middle Devonian of Kentucky, and from the basal Silurian in central Ohio. The strata become thinner from east to

[3] Some Trenton oil has been found on the south edge of the Adirondack region but is not of commercial importance.

west. The Silurian, Devonian, and Mississippian, which are nearly 12,000 feet thick in central Pennsylvania, and still thicker farther east, are only 3,500 feet thick in eastern Ohio and about 2,000 feet thick in central Ohio.

Figure 4 shows more in detail and on a larger scale the principal oil and gas sands found: (1) in the Bradford field, (2) in the western Pennsylvania fields, (3) in southeastern Ohio. Younger sands are not present in the Bradford field because the northward regional rise

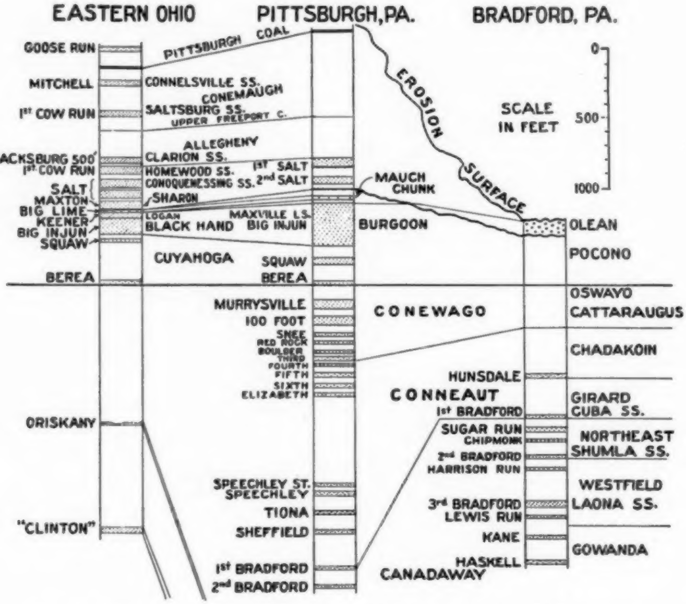

FIG. 4.—Chart showing oil and gas sands as found in eastern Ohio, western Pennsylvania, and Bradford district.

brought the Pennsylvanian to the surface and because the pre-Pennsylvanian erosion at the north and west removed all of the Mauch Chunk and the top of the Pocono. In fact, all of the Pocono is gone in the Olean region of southern New York, the basal Pennsylvanian lying on the Upper Devonian.

In the general area of Pittsburgh there are, as indicated, many producing sands, the deeper sands as a rule producing only gas. In eastern Ohio all Devonian sands are absent, having been replaced by shale

and limestone, except the Oriskany which is very thin and spotty, and a small area of the Third sand in the northeast corner of the state.

The Tuscarora ("Clinton") at the base of the Silurian is a large gas producer in central Ohio and has produced some oil. The oil produced in eastern Ohio has come mainly from the Berea and higher sands. The Berea, which extends over all of southeastern Ohio, has probably been the principal producer.

Figure 5 attempts to portray, without reference to rock thickness, and only crudely, as many matters of correlation are still unsettled, the changing conditions under which the rocks were laid down, conditions that largely determined the occurrence of oil and gas source rocks. In general the continental facies of most of the beds at the east grades westward through sandy shore deposits, shaly off-shore deposits, to limestone and black shale at the west. Obviously there was a succession of sinking seas feeding from the east, in which the shore line gradually moved westward, carrying the successive phases of sedimentation farther and farther west.

At the east, in each instance, land deposits were subject to exposure that oxidized any plant or animal remains, as it did the iron compcunds, turning the rocks red. At the west were sandy deposits (Chemung phase) consisting of alternating sand and mud, teeming with life. Farther west waters were receiving only the finer deposits (Portage phase) and still farther west and south was a sargasso sea, with black slime bottom, fertile material for the production of oil and gas, but with no coarse-grained, porous rocks to serve as reservoirs. Exceptions are found in (1) the Tuscarora sandstone, which stretched west to central Ohio where it has been a great source of gas, (2) the Oriskany, which extends west into Ohio but is only locally present and commonly thin, and (3) the Berea, which appears to have come from the west or north and thins out toward the east. It is thus obvious that regardless of subsequent folding the character of the rocks has been a limiting factor in the distribution of oil and gas in this area, and the limiting factor on the west side of the axis of the fields.

On the boundary between Tennessee and Kentucky and Virginia, are the same noticeable thinning of the post-Ordovician strata from east to west accompanied by the same thinning of the sandy beds westward to be replaced by shale and limestone. This is shown in Figure 6. In Figure 7 the sections at Bristol and in Overton and Pickett counties make these changes clearer.

The thinning of the Devonian through the Appalachian region is shown in another way in Figure 8, by the use of isopachous lines or lines or equal thickness. It has been supposed that these deposits

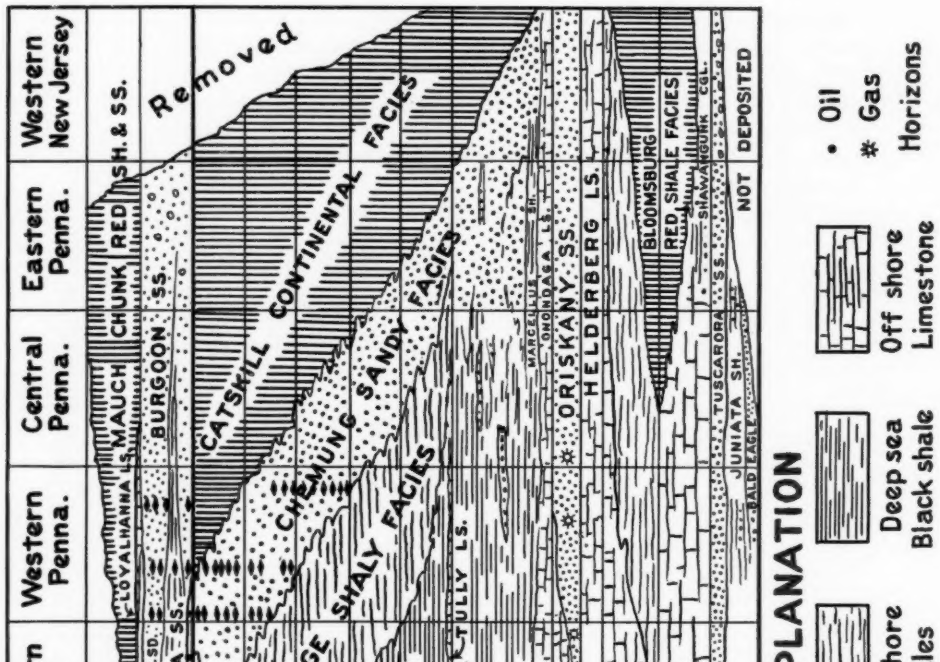

FIG. 5.—Chart showing changing rock facies from east to west between New Jersey and Ohio.

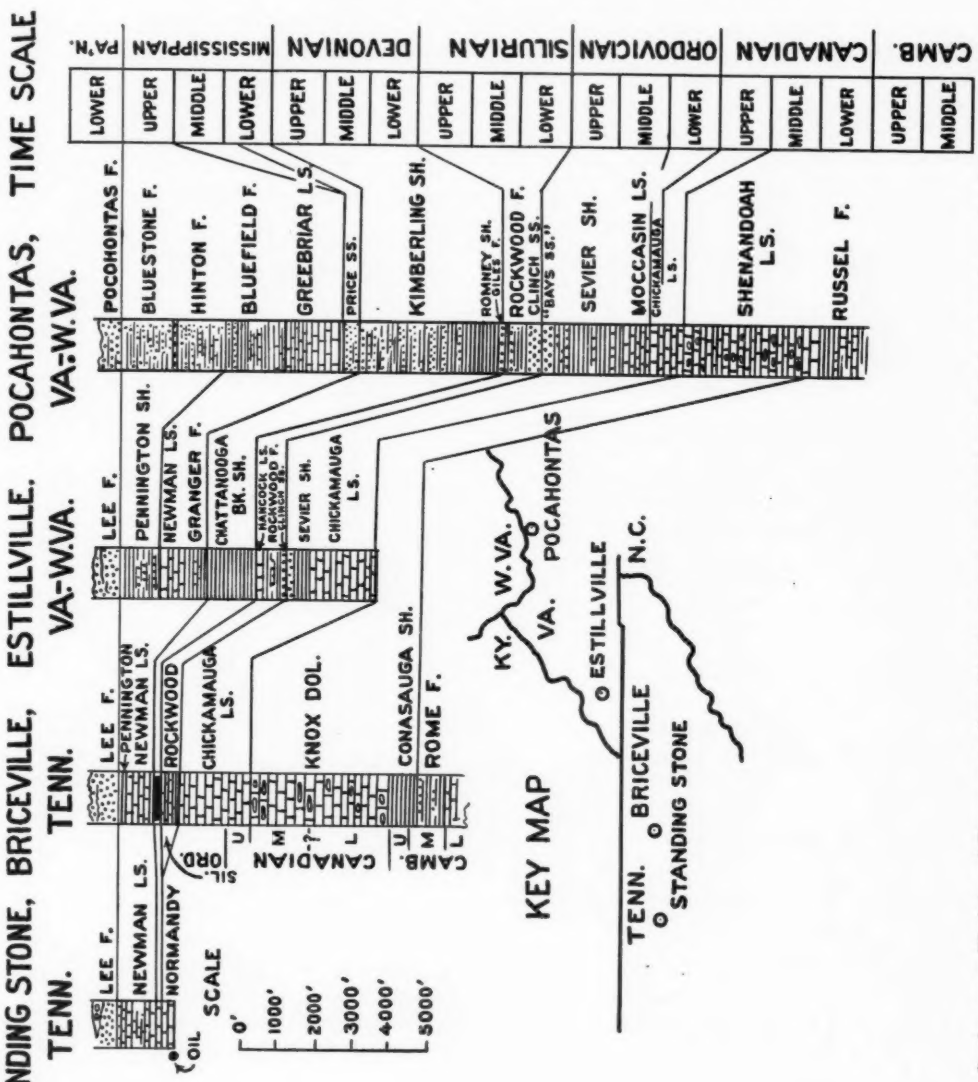

FIG. 6.—Section across Virginia and Tennessee to show thinning of strata westward, and replacing of sandstones by shale and limestone.

represented a vast delta, or deltas, laid down in the Devonian sea and thinning to a feather edge against the Cincinnati-Nashville arch, finally represented at the west by only a few feet of black shale or none.

We have now presented two reasons for the limitations of the Appalachian oil and gas fields to the narrow belt previously shown and for the lack or meagerness of the deposits toward the southwest:

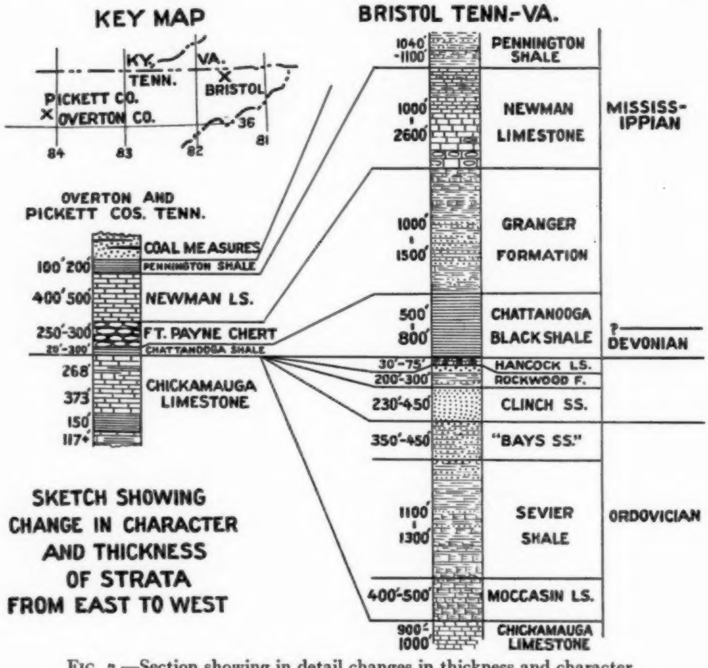

FIG. 7.—Section showing in detail changes in thickness and character of rocks from east to west in northern Tennessee.

(1) the thinning of all the beds toward the west and south and particularly the disappearance of the sandstone reservoirs, and (2) at the east the presence of thousands of feet of continental beds in which conditions for the preservation of oil- and gas-producing substances were unfavorable.

There still remain to be considered the results of the action of mountain-building forces on the occurrence and distribution of oil and gas. The great thrust movement occurred at the end or toward the

latter part of Carboniferous time. In the axis of the Appalachian basin of sedimentation 25,000–30,000 feet of sediment had accumulated. We are not concerned here with the nature of the push, or thrust, but only with the results. It has been estimated that this vast body of sediments, amounting in Pennsylvania alone to more than 250,000 cubic miles, was shoved westward until narrowed by 100–200 miles. At the east the strata were not only folded but crushed and crumpled and

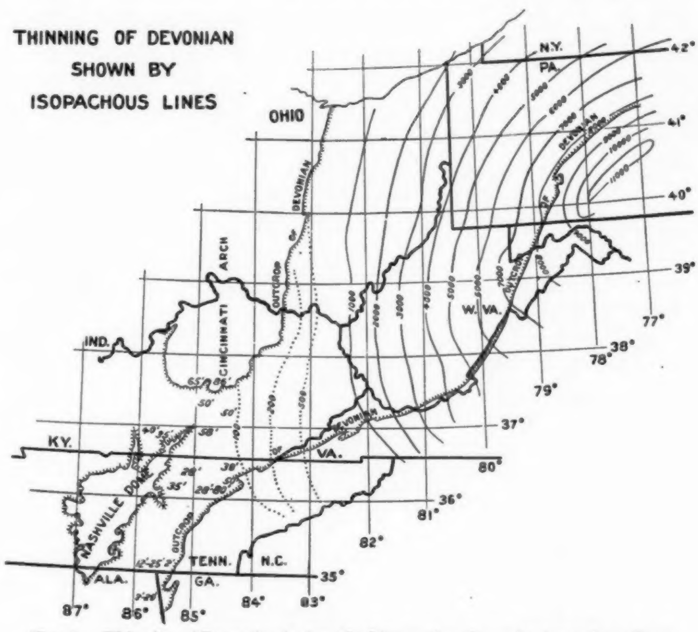

FIG. 8.—Thinning of Devonian in Appalachian region shown by isopachous lines.

even metamorphosed into schist, marble, slate, and quartzite. The coal beds involved in the upper part of the mass were devolatilized in the east into anthracite and farther west into low-volatile coals, becoming high-volatile coals only in the northwest part of Pennsylvania and in a belt extending southwest from there. The black shales of the Appalachian region when distilled may yield ½ barrel of oil to the ton at the west but reveal only carbon at the east; thus obviously any oil-producing material at the east was completely dissipated to leave only the pure carbon residue. Arthur Keith has suggested that the present Allegheny front was approximately at the line of the western

edge of the early Cambrian sea which may have therefore formed a buttress against which the great movement was naturally halted. Beyond that line pressure and folding were less severe and gradually disappeared in central Ohio, Kentucky, and Tennessee. But apparently the great thrust moved somewhat crosswise on the original lines of sedi-

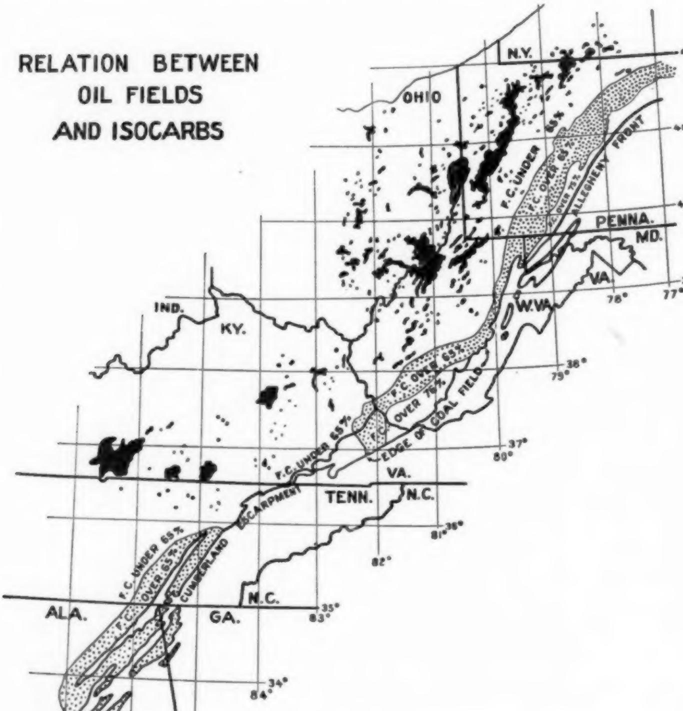

FIG. 9.—Map showing relation of Appalachian oil field to 65 per cent isocarb.

mentation, which extended more clearly north and south, as suggested by the isopachous lines in Figure 8. As a result, the stratigraphic conditions which were favorable for the occurrence of oil and gas in western Pennsylvania, if traced a short distance southward (not southwestward), are found to extend into the area of more intense folding, and in West Virginia they cross the Allegheny front and be-

come involved in the folding and faulting, uplift and subsequent erosion, characteristic of the area east of the Allegheny front; so that the area of eastern Kentucky and east-central Tennessee, where structural conditions are favorable for the occurrence of gas and oil, contain only black shale and limestone, corresponding with the rocks of Ohio and eastern Indiana. It is to be remembered that the Nashville dome, and to a lesser extent the Cincinnati arch, had been positive elements during a large part of Paleozoic time so that the various series and groups tend to thin over them or to feather out against them.

The relation of the present oil fields to the isocarb lines is shown in Figure 9.

Practically all of the oil fields are in the area under isocarb 65. As a matter of fact, most of the fields indicated near that isocarb have been very small, some of them classed as not commercial. Most of the fields occur in the area below isocarb 60. Natural gas occurs abundantly below isocarb 65, less abundantly in the area between isocarb 65 and 75, and a little gas occurs above isocarb 75, as in the central part of Somerset County, Pennsylvania.

A feature that must not be overlooked in this general connection is that the isocarbs move westward with depth. Probably that accounts for the absence of oil in quantity in Pennsylvania below depths of 3,000 feet, though gas is found at a depth of 7,000 feet or more. There have been a few exceptions, notably the W. L. Burdette well in the Oriskany in Kanawha County, West Virginia (oil at 4,822 feet). Oil has also been found at depth in central Ohio.

Having briefly outlined the geologic conditions that have determined the horizontal and vertical distribution of oil and gas in the Appalachian region, let us review with equal brevity the discovery and development of these deposits.

The Indians are generally credited with having known and used crude petroleum for rheumatism and other ailments before the coming of white men. Father de la Roche d'Aillon mentioned their possession of it in 1627. Some of this oil doubtless came from the oil spring in the Cuba sandstone (First Bradford sand) at Cuba, Allegany County, New York, which was mentioned in 1656 and again in 1721 by other French Jesuit missionaries.

The oil spring of Oil Creek near Titusville was known to white men as early as 1750 and a little later oil was obtained in quantity by soaking and wringing out blankets. This oil, like that from Cuba, was sold as "Seneka" oil for medicinal purposes. Oil seeps and gas springs were known throughout the Appalachian region and early in the nineteenth century a search for salt revealed many other sources. An at-

tempt in 1806 to increase the supply of salt water from the salt springs near the mouth of Campbells Creek above Charleston, West Virginia, by David and Joseph Ruffner, led to the development of drilling tools and casing, made at first of wood, later of metal. Later drilling was improved by the invention of jars by William Morris in 1831. Drilling for salt spread rapidly and most of these wells in the Ohio and Kanawha valleys yielded some oil and gas, so much so that for a long time the Kanawha was known as "Old Greasy." In 1814 a well drilled in Duck County, West Virginia, struck oil at 475 feet, which flowed 30–60 gallons at each eruption and was still flowing a barrel a week in 1833. In 1815 gas was struck within the limits of Charleston, West Virginia; in 1818 a crew drilling for salt in McCreary County, Kentucky, struck oil, and in 1820 a well drilled for salt on the Obey River, Tennessee, flowed oil until the river was covered with oil. The river later caught fire and produced a bonfire. Again in 1837 another salt well on the Obey River 4 miles below the mouth of Wolf Creek encountered a large flow. Writing in 1826 in the *American Journal of Science*, Dr. S. P. Hildreth stated that as early as 1814 drilling for salt encountered gas that threw the water 30 or 40 feet out of the well, and that wells drilled in Washington County to depths of 400–500 feet invariably struck gas, and two wells in Guernsey County discharged vast quantities of "petroleum or Seneka oil." He noted that this oil sold for a profit for use in lamps, yielding a "clear, brisk light" and suggested its use in street lamps.

About this time petroleum began to be used for lamps in homes, workshops, and factories, having been so used in England since 1760, where it was obtained by distilling coal. In 1846 Abe Gesner, in this country, patented a process for distilling kerosene from coal which, by 1860, had led to the formation of 55 companies for the distillation of coal-oil from cannel coal, the coal-oil selling for 60–70 cents per gallon.

In the meantime Bosworth, Wells and Company of Marietta, Ohio, had developed a business in buying and selling oil obtained from salt wells of West Virginia and Ohio. At one time they shipped hundreds of barrels to the people in Pittsburgh, Peoria, St. Louis, Chicago, Cincinnati, Baltimore, Philadelphia, and New York. The oil brought 33 cents per gallon and later 40 cents. By 1854 oil was in common use and in that year the first deed conveying oil rights in Pennsylvania was signed. By that time the presence of oil was known in many places throughout the Appalachian oil and gas region.

As a result of successful drilling for oil by Drake at Titusville in 1859, drilling spread rapidly in those areas where the presence of oil

and gas was already known. Thus the Rathbone Brothers, who in 1842 had purchased 1,000 acres in the Little Kanawha and Burning Spring Run region, and drilled for salt, struck so much oil that they abandoned the well drilled for salt and skimmed and sold the oil. In 1859 they installed a pump in the well and began pumping oil and the well produced several barrels a day. This was possibly the first well to be pumped. Probably the first well to be drilled for oil in West Virginia was drilled on the Rathbone place in 1859, completed in May, 1860, to a depth of 303 feet, and produced 100 barrels a day.

Naturally the finding of oil on Oil Creek led to a rapid development in Pennsylvania. Flowing wells appeared on Oil Creek in 1861 and soon many gushers flowed 3,000–4,000 barrels a day. By 1865 development here and there had extended as far south as the southwest corner of the state with drilling in the intermediate territory and the Bradford field beginning in the later 1860's. Natural gas was piped to Titusville in 1872 and 2 years later was used in iron-making. In 1875 the first well in the Bradford field was drilled. The field reached its maximum in 1881, and in 1883 gas was first piped to Pittsburgh. In 1884 a well on Thorn Creek flowed 12,000 barrels a day. In 1891 the McDonald field was discovered, and one well flowed 730 barrels per hour.

Subsequent development has to do mainly with the extending of the fields and deeper drilling for gas, both in Pennsylvania and West Virginia. For many years the deepest wells in the world were in those states. In the early years of the present century, repressuring of oil wells in the Bradford and other fields was begun.

Though drilling began in all of the Appalachian states, including New York, immediately after the drilling of the Drake well, most of the production continued to come from Pennsylvania for the first 10 or 15 years. New York became a large producer with the opening of the Bradford field and in 1882 produced 6 million barrels. In 1884 Ohio and West Virginia had a combined production of only 180,000 barrels against 20,541,000 barrels from Pennsylvania, and 2,231,000 barrels from New York. Kentucky and Tennessee in the same year had a combined production of only 4,000 barrels. In 1933 Pennsylvania had produced 898,360,000 barrels and New York 85,454,000 barrels. Pennsylvania reached the high of 31,424,000 barrels in 1891, then declined to 7,418,000 in 1921. Subsequently repressuring has raised the production to about 18 million barrels.

Production in West Virginia reached the high of 16,168,000 barrels in 1900 and had declined by 1933 to 3,815,000 barrels. Ohio reached a maximum for the whole state of 23,941,000 barrels in 1896

and has since declined to 4,235,000 barrels in 1933, of which 3,203,000 barrels were from eastern and central Ohio and 1,032,000 from northwestern Ohio.

Kentucky and Tennessee remained very small producers until the beginning of the present century, when production took a small spurt, rising to 1,217,000 barrels for the two states. In 1910 production had dropped back to 409,000 barrels in Kentucky and to none in Tennessee. In 1916 production again reached 1 million in Kentucky with 1,000 barrels from Tennessee, increasing to 9,278,000 barrels in Kentucky and 15,000 barrels in Tennessee in 1919. From that high, Kentucky production had declined to 4,608,000 barrels in 1933 and production in Tennessee had reached 60,000 barrels in 1927 and declined to 5,000 barrels in 1933. The principal producer in Kentucky had been a thin limestone formerly correlated with the Onondaga or "Corniferous" limestone, but now thought to be of middle Hamilton age. Smaller production has come from many horizons ranging from the Pennsylvanian to the Ordovician. In Tennessee, as previously pointed out, most of the post-Ordovician strata become thin or disappear against the Nashville dome, and production has come mainly from the Fort Payne chert of Lower Mississippian age and from the Chickamauga limestone of Ordovician age.

Alabama has revealed many showings of oil and gas but only one oil well and one gas pool. Drilling began in the period from 1865 to 1867 near some oil-tar springs in Lawrence County. One well struck "some oil" at 1,500 feet in Trenton limestone. From 1902 to 1906 drilling in Fayette County, following the report of a showing of oil in a diamond-drill hole sunk for coal, produced about 6,000,000 cubic feet or less of gas per well at 1,400 feet in the Fayette sandstone in the Coal Measures. By 1929 about 250 wells had been drilled covering most of the state considered as possible oil or gas territory.

As to the future, estimates made by the State Surveys of Pennsylvania, Ohio, and West Virginia, in coöperation with the leading oil geologists of the Pennsylvania Grade Crude Oil territory indicate possibly 1½ billion barrels of oil as still in the ground. Whether it can be recovered remains to be seen.

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VOL. 22, NO. 4 (APRIL, 1938), PP. 431-482

BIBLIOGRAPHY OF GEOLOGIC STRUCTURE MAPS AND CROSS SECTIONS OF AREAS IN OIL AND GAS STATES EAST OF THE MISSISSIPPI RIVER, AND SOME PRODUCING STATES IN THE MID-CONTINENT REGION[1]

ALABAMA	KENTUCKY	NEW YORK
ARKANSAS	LOUISIANA	OHIO
ILLINOIS	MICHIGAN	PENNSYLVANIA
INDIANA	MISSISSIPPI	TENNESSEE
KANSAS	MISSOURI	WEST VIRGINIA

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FOREWORD

This list of structure maps and cross sections of areas that have been exploited for oil and gas in eastern and Mid-Continent states was begun merely for the writer's own use in official work. However, the late Sidney Powers, on the occasion of one of his visits to the offices of the Geological Survey, suggested that the list be published by the American Association of Petroleum Geologists for the convenience of those especially interested in the geology and technology of oil and gas. It is therefore offered with this intention. To condense the list as much as possible the references have been shortened to the limit of usefulness, and titles of papers that the maps and cross sections accompany have not been given.

Grateful acknowledgment is made of the coöperation of several State geologists and of critical reading of parts of the manuscript by several of the geologists in the Federal Survey.

ALABAMA

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Structure section across Birmingham Quadrangle, *ibid.*, Fig. 1.

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[1] Published by permission of the director, Geological Survey. Manuscript received, November 13, 1937.

[2] Assistant geologist, Geological Survey, United States Department of the Interior.

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Structure map of Berry district, Fayette and Tuscaloosa counties, D. R. Semmes, *ibid.*, Map 5.

FRANKLIN COUNTY

Structure map of Cedar Creek Valley, *ibid.*, Map 6.

JEFFERSON COUNTY

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Structure section across Birmingham Quadrangle, Charles Butts, *ibid.*, Fig. 1.

Map and cross section of Birmingham Quadrangle, *ibid.*, *Folio 175* (1910). Scale, 1:125,000.

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LAWRENCE COUNTY

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MARION COUNTY

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Map of county showing structure contours on coal bed, M. L. Nebel, *Illinois Geol. Survey Bull. 40* (1919), Pl. 1. Scale, ⅜ inch: 1 mile.

CASS COUNTY

Cross section from Beardstown to Indiana-Illinois state line, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pl. 11.

CENTRAL

Map showing structure contours on coal No. 5 in Fulton, Peoria, Mason, Tazewell, McLean, Logan, DeWitt, Macon, Menard, and Sangamon counties, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 25* (1921), Pl. 1. Scale, 4 inches: 1 mile.

Structure of central part of Illinois Basin, J. M. Weller and A. H. Bell, *Illinois Geol. Survey Rept. Investig. 40* (1936), Fig. 2. *Ibid.*, *Oil and Gas Jour.* (November 26, 1936).

Structure map of Ste. Genevieve limestone in Clay City area, Clay County, and Noble area, Richland County, D. Hager and A. F. Hoffman, *Oil and Gas Jour.* (December 23, 1937).

CENTRAL-WESTERN

Columnar sections across central-western Illinois, R. S. Blatchley, *Illinois Geol. Survey Bull. 28* (1914), Pl. 1.

CLARK COUNTY

Structure map of Martinsville area in Clark County, G. F. Moulton, *Illnois Geol. Survey Illinois Petrol. 4* (August 28, 1926), Fig. 1.

Structure map of northern part of Clark County (Westfield pool), L. A. Mylius, *Illinois Geol. Survey Bull. 54* (1927), Pl. 22-A.

Structure map of pools in central part of county, *ibid.*, Pl. 22-B.

Structure map of Westfield pool, *ibid.*, Pl. 26.

Structure map of North Casey pool, *ibid.*, Pl. 28.

Structure map of Martinsville pool, *ibid.*, Pl. 29.

Structure map of South Johnson pool, *ibid.*, Pl. 30.

Structure section through Siggins to Martinsville pool, *ibid.*, Pl. 6.

Cross section of North Casey pool, *ibid.*, Pl. 16.

Cross section of Casey and Martinsville pools, *ibid.*, Pl. 17.

Cross section of North Johnson pool, *ibid.*, Pl. 18.

Structure map of Clark County, G. F. Moulton and J. Young, *Illinois Geol. Survey Illinois Petrol. 14* (March 17, 1928), Fig. 3.

CLAY COUNTY

Structure map of parts of Clay and Marion counties, J. M. Weller and A. H. Bell, *Illinois Geol. Survey Rept. Investig. 40* (1936), Fig. 4. *Ibid.*, *Oil and Gas Jour.* (November 12, 1936).

CLINTON COUNTY

Geologic maps of Belleville-Breeze quadrangles (Clinton, St. Clair, and Madison counties), showing structure contours on coal bed, also geologic sections, J. A. Udden, *U. S. Geol. Survey Geol. Folio 195* (1915).

Map showing structure in Centralia area (Clinton, Washington, and Marion counties), Stuart St. Clair, *Illinois Geol. Survey Bull. 35* (1917). Scale, ¾ inch: 1 mile.

Map showing structure in Carlyle-Centralia quadrangles, E. W. Shaw and Stuart St. Clair, *U. S. Geol. Survey Geol. Folio 216* (1923).

Structure map of Hoffman area, A. H. Bell and J. H. Markley, Jr., *Illinois Geol. Survey Petrol. 5* (October 16, 1926), Fig. 2.

Structure map of Centralia-Sandoval area, A. H. Bell, *ibid. 10* (July 23, 1927), Fig. 1. Scale ¾ inch: 1 mile.

COLES AND EDGAR COUNTIES

Illinois Geol. Survey Bull. 44 (1923), Pl. 7.

Structure map of Oakland dome, L. A. Mylius, *ibid.*, *Bull. 54* (1927), Pl. 20.

CRAWFORD COUNTY

Map of southern half of Crawford County oil field showing structure contours on Robinson sand, R. S. Blatchley, *Illinois Geol. Survey Bull. 22* (1913), Pl. 5. Scale, 2 inches: 1 mile.

Small contour map showing surface formation of Birds oil sands, J. L. Rich, *ibid. Bull. 33* (1916), Fig. 12.

Structure on 600-foot gas sand in Flat Rock pool, F. B. Tough, S. H. Williston, and T. E. Savage, *ibid.*, *Bull. 40* (1919), Pl. 10.

Structure on Flat Rock sand, *ibid.*, Pl. 11.

Cross section of Bellair pool, L. A. Mylius, *Illinois Geol. Survey Bull. 54* (1927), Pl. 19.

Structure map of Bellair pool, *ibid.*, Pl. 31. Scale, 4 inches: 1 mile.

CUMBERLAND COUNTY

Structure map of Siggins, Vevay Park, and York pools, L. A. Mylius, *Illinois Geol. Survey Bull. 54* (1927), Pl. 27. Scale, 4 inches: 1 mile.

Cross section of Siggins pool, *ibid.*, Pl. 15.

EASTERN

Map showing something of structure of eastern Illinois (Lawrence, Crawford, Clark, Coles, Edgar, Vermilion, Douglas, and Champaign counties), L. A. Mylius, *Illinois Geol. Survey Bull. 44* (1919), Pl. 1.

Stratigraphic and structure sections, *ibid.*, Pls. 2–3.

Structure maps and sections of counties in east-central Illinois, L. A. Mylius, *Illinois Geol. Survey Bull. 54* (1927). (Douglas, Edgar, Coles, Clark, and parts of adjoining counties.)

FULTON COUNTY

Map of Canton and Avon quadrangles (Fulton and Knox counties), showing structure on coal beds, after T. C. Savage, *Illinois Geol. Survey Coal Mining Investig. Bull. 26*, (1921) Pl. 5. Scale, 1 inch: 2 miles.

Map of Canton Quadrangle (Fulton and Knox counties) structure, T. E. Savage, *Illinois Geol. Survey Bull. 33*, Pl. 2; cross section, Fig. 6; Avon Quadrangle, Pl. 3. Scale, 1:62,500.

Map of Avon-Canton quadrangles (Fulton-Knox counties), showing geology and structure, T. E. Savage, *Illinois Geol. Survey Bull. 38* (1922), Pl. 1. Scale, 1:62,500.

Structure map of area near Canton, G. F. Moulton, *Illinois Geol. Survey Rept. Investig. No. 6* (1925), Fig. 3.

Structure map of area near Babylon, *ibid.*, Fig. 4.

Structure map of Avon area (Fulton, Knox, and Warren counties), *ibid.*, Fig. 5.

GALLATIN AND SALINE COUNTIES

Geologic map showing structure of parts of Equality and Shawneetown quadrangles, with cross sections, Charles Butts, *Illinois Geol. Survey Bull. 47* (1925), Pl. 1. Scale, 1:62,500.

GREENE COUNTY

Structure map of parts of Greene, Madison, and Jersey counties, D. M. Collingwood, *Illinois Geol. Survey Rept. Investig. 30* (1933), Pl. 1. Scale, 1 inch:2 miles.

GRUNDY AND KENDALL COUNTIES

Map showing structure, G. H. Cady *et al.*, *Illinois Geol. Survey Coal Mining Investig. Bull. 10* (1915), Pl. 1.

Map showing structure in Morris Quadrangle, H. E. Culver, *Illinois Geol. Survey Bull. 43* (1922), Pl. 3. Scale, 1:62,500.

HANCOCK COUNTY

Section from Clark County, Missouri, and Hancock County, Illinois, F. Krey, *Illinois Geol. Survey Bull. 45* (1924), Pl. 15. Structure map, Pl. 1. Structure sections, Pl. 3.

Small structure map of the Warsaw anticline, A. H. Bell, *Illinois Geol. Survey Petrol. 24* (1932), Fig. 3.

HANCOCK, MCDONOUGH, AND SCHUYLER COUNTIES

Map of Colchester-Macomb quadrangles, showing structure, W. C. Morse and F. H. Kay, *Illinois Geol. Survey Bull. 31* (1915), Pl. 3. Scale, about $\frac{5}{8}$ inch:1 mile. *Ibid.*, *Bull. 30*, Pl. 2; *Bull. 23*, Pl. 2, shows contours on coal beds.

Geologic maps of Colchester-Macomb quadrangles, showing structure contours on coal beds, Henry Hinds, *U. S. Geol. Survey Geol. Folio 208* (1919).

Small structure map of Colmar anticline, W. C. Morse, *ibid.*, Fig. 14.

See *Illinois Geol. Survey Bull. 43*, LaHarpe-Good Hope quadrangles listed under Henderson County.

Structure map of the Warsaw anticline, A. H. Bell, *Illinois Geol. Survey Petrol. 24* (1932), Fig. 3.

HARDIN, POPE, AND SALINE COUNTIES

Structure map of parts of these counties, Charles Butts, *Illinois Geol. Survey Bull. 41* (1920), Pl. 3. Scale, 1 inch:1 mile. *Ibid.*, *Bull. 35* (1917), Pl. 9.

HENDERSON COUNTY

Structure map of Good Hope Quadrangle, M. L. Nebel, *Illinois Geol. Survey Bull. 40* (1919), Pl. 2. La Harpe Quadrangle, Pl. 3. Scale, 1:62,500.

Geologic map with structure contours of LaHarpe-Good Hope quadrangles (parts of Henderson, Warren, McDonough, and Hancock counties), M. L. Nebel and T. E. Savage, *Illinois Geol. Survey Bull. 43* (1921), Pl. 1. Scale, 1:62,500.

Structure map of Media area, A. H. Bell and L. E. Workman, *Illinois Geol. Survey Petrol. 13* (January 28, 1928), Fig. 3. Scale, about 1 inch:1 mile.

JACKSON COUNTY

Map showing geologic structure of Murphysboro Quadrangle (Jackson and Perry counties), contours on coal beds, E. W. Shaw, *Illinois Geol. Survey Bull. 16* (1910), Pl. 32. Scale, 1 inch:1 mile.

Map showing structure contours on coals No. 2 and No. 6, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 16* (1917), Pl. 1. Scale, 1 inch: 4 miles.

Geologic structure of Ava area, Stuart St. Clair, *Illinois Geol. Survey Bull. 35* (1917), Pl. 7. Scale, about ¾ inch: 1 mile. Cross section of same, showing Campbell Hill anticline, Fig. 12.

JACKSON, UNION, AND WILLIAMSON COUNTIES

Structure of the Carbondale Quadrangle, J. E. Lamar, *Illinois Geol. Survey Bull. 48* (1925), Pl. 4.

East-west cross section of northern part of Carbondale Quadrangle, *ibid.*, Pl. 3.

JERSEY COUNTY

(See Greene County).

JO DAVIESS COUNTY

Map showing structure on Galena dolomite in Galena Quadrangle, G. H. Cox, *Illinois Geol. Survey Bull. 21* (1914), Pl. 20. Scale, 4 inches: 1 mile.

Geologic map with structure contours on Galena of Galena-Elizabeth quadrangles, A. C. Trowbridge and E. W. Shaw, *Illinois Geol. Survey Bull. 26*, Pl. 4. Scale, 1:62,500.

Geologic maps showing structure contours on Galena dolomite in Galena-Elizabeth quadrangles, E. W. Shaw and A. C. Trowbridge, *U. S. Geol. Survey Geol. Folio 200* (1916). Scale, 1:62,500.

KANKAKEE COUNTY

Map showing structure of Herscher Quadrangle, L. F. Athy, *Illinois Geol. Survey Bull. 55* (1928), Pl. 1. Scale, 1:62,500.

KENDALL AND GRUNDY COUNTIES

Geologic map showing contours on No. 2 coal and St. Peter sandstone in Morris Quadrangle, H. E. Culver, *Illinois Geol. Survey Bull. 43* (1922), Pl. 3. Scale, 1:62,500.

KNOX AND WARREN COUNTIES

Structure map of Galesburg Quadrangle, R. S. Poor, *Illinois Geol. Survey Petrol. 9* (June 18, 1927), Fig. 2. Scale, 1 inch: 3 miles.

LA SALLE AND BUREAU COUNTIES

Structure of Pennsylvanian strata, La Salle anticline, *Illinois Geol. Survey Bull. 36*, Pl. 8. Scale, about 1 inch: 25 miles.

Map showing structure of St. Peter sandstone in Hennepin and La Salle quadrangles, G. H. Cady, *Illinois Geol. Survey Bull. 37* (1919), Pl. 3. Structure map of quadrangles, Pl. 2.

Map of Longwall district, *Illinois Geol. Survey Coal Mining Investig. Bull. 10*, Pl. 1.

LAWRENCE COUNTY

Map of Lawrence County oil field showing structure contours on Buchanan sand, R. S. Blatchley, *Illinois Geol. Survey Bull. 22* (1913), Pl. 7; "Gas" sand, Pl. 8; Kirkwood sand, Pl. 9; Tracey sand, Pl. 10; McClosky sand, Pl. 11; section along crest of LaSalle anticline and through center of oil

field, Pl. 12; section across northern end of field, Pl. 13; section across dome in Petty Township, Pl. 14; section across southern end of field, Pl. 15.

Map showing structure in the Vincennes Quadrangle (Lawrence and Wabash counties), J. L. Rich, *Illinois Geol. Survey Bull. 33* (1916), Pl. 8. Scale 1:62,500.

Map showing structure contours on Kirkwood sand in Lawrence County, G. H. Cady, *Illinois Geol. Survey Bull. 36* (1916), Pl. 3; structure section, Pl. 4.

Structure map of area southwest of Murphy pool, A. H. Bell, *Illinois Geol. Survey Petrol. 16* (June 30, 1928), Fig. 5. Scale, 1⅜ inches: 1 mile.

Structure maps of parts of Lawrence County, A. H. Bell and R. J. Piersol, *Illinois Geol. Survey Petrol. 22* (June, 1932).

LIVINGSTON COUNTY

Cardiff field, structure contours on coal No. 2, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 10* (1915), Pl. 5.

MACON AND CHRISTIAN COUNTIES

Structure map of Decatur and vicinity, D. M. Collingwood, *Illinois Geol. Survey Rept. Investig. 1* (1924), Pl. 1. Cross section of same, Fig. 1.

MACOUPIN COUNTY

Cross section of Carlinville area, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pl. 18.

Map showing structure contours in Carlinville oil field, F. H. Kay, *Illinois Geol. Survey Bull. 20* (1915), Pl. 8; structure section through the field, Pls. 9–10.

Map showing structure in Carlinville field, W. Lee, *Illinois Geol. Survey Bull. 31* (1915), Fig. 18; sections across the field, Pl. 8.

Map showing structure of Gillespie Quadrangle, *ibid.*, Pl. 9. Scale, 1: 48,000. Also *Bull. 30*, Fig. 2.

Structure of Staunton gas field, L. A. Mylius, *Illinois Geol. Survey Bull. 44* (1919), Pls. 1–2.

Geologic maps of Gillespie-Mt. Olive quadrangles (Macoupin and Montgomery counties), showing structure contours on coal bed, W. Lee, *U. S. Geol. Survey Geol. Folio 220* (1926). Scale, 1:62,500.

MADISON, MONTGOMERY, AND BOND COUNTIES

Structure map of Sorento dome, A. H. Bell, *Illinois Geol. Survey Petrol. 6* (December 4, 1926), Fig. 2. Scale, 1 inch: 2 miles. Also in *Trans. Illinois Acad. Sci.* (1928), Vol. 20.

MADISON AND ST. CLAIR COUNTIES

Structure sections of St. Louis district, N. M. Fenneman, *U. S. Geol. Survey Bull. 438* (1911), Pl. 6.

MADISON, JERSEY, AND GREENE COUNTIES

Structure map, D. M. Collingwood, *Illinois Geol. Survey Rept. Investig. 30* (1933), Pl. 1. Scale, 1 inch: 2 miles.

MARION COUNTY

Cross section, Centralia to Patoka, showing positions of sands, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pls. 12–13.

Contour map showing geologic structure and development in Marion County oil fields, *ibid.*, Pl. 14.

MARION AND CLAY COUNTIES

(See Clay County.)

MARION AND CLINTON COUNTIES

Cross section, Marion to Salem, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pl. 10.

Geologic maps showing structure contours on No. 6 coal, Carlyle-Centralia quadrangles, E. W. Shaw, *U. S. Geol. Survey Geol. Folio 216* (1923). Scale, 1:62,500.

Structure maps of areas near Centralia, A. H. Bell, *Illinois Geol. Survey Petrol. 4* (August 28, 1926), Figs. 2, 3.

Structure map of Junction City area, A. H. Bell and J. H. Markly, Jr., *Illinois Geol. Survey Petrol. 5* (October 16, 1926), Fig. 1.

Structure map of Sandoval pool, A. H. Bell, *Illinois Geol. Survey Petrol. 10* (July 23, 1927), Figs. 3–4; structure map of Centralia-Sandoval area, Fig. 1. Scale, $\frac{3}{4}$ inch:1 mile.

MCDONOUGH AND WARREN COUNTIES

Map showing structure in Good Hope Quadrangle, M. L. Nebel, *Illinois Geol. Survey Bull. 40* (1919), Pl. 2. Scale, 1:62,500.

Structure map of area near Good Hope, G. F. Moulton, *Illinois Geol. Survey Rept. Investig. 6* (1925), Fig. 6.

MCDONOUGH, SCHUYLER, AND HANCOCK COUNTIES

Structure map of Colchester-Macomb quadrangles, Henry Hinds, *Illinois Geol. Survey Bull 30* (1915), Pl. 2. Scale, about $\frac{5}{8}$ inch:1 mile.

Map showing structure contours on coal beds in the Colchester-Macomb quadrangles, Henry Hinds, *Illinois Geol. Survey Bull. 23* (1917), Pl. 2. Scale, about $\frac{5}{8}$ inch:1 mile.

MCDONOUGH, WARREN, HENDERSON, AND HANCOCK COUNTIES

Structure map of LaHarpe Quadrangle, M. L. Nebel, *Illinois Geol. Survey Bull. 40* (1919), Pl. 3. Scale, 1:62,500.

Map showing structure in LaHarpe and Good Hope quadrangles, M. L. Nebel and T. E. Savage, *Illinois Geol. Survey Bull. 43* (1921), Pl. 1. Scale, 1:62,500.

MERCER AND WARREN COUNTIES

Structure map of Alexis Quadrangle, H. R. Wanless, *Illinois Geol. Survey Petrol. 8* (April 16, 1927), Fig. 2. Scale, about 1 inch:3 miles.

Structure map of bedrock in Alexis Quadrangle, *ibid.*, *Bull. 57* (1929), Pl. 4. Scale, 1:62,500.

MONROE COUNTY

Structure map of Valmeyer anticline in the vicinity of Posten School, L. A. Mylius, *Illinois Geol. Survey Press Bull.* (November 19, 1921).

Structure map of Waterloo field, J. E. Lamar, *Illinois Geol. Survey Petrol. 5* (October 16, 1926), Fig. 3. Scale, about $1\frac{1}{2}$ inches:1 mile.

Structure map of Waterloo anticline (and Dupo in St. Clair County),

A. H. Bell, *Illinois Geol. Survey Petrol. 17* (March 2, 1929), Fig. 2. Scale, about $\frac{7}{16}$ inch: 1 mile.

Structure map of area near Renault, G. F. Moulton, *Illinois Geol. Survey Petrol. 18* (November 12, 1929), Fig. 3. Scale, $1\frac{1}{4}$ inch: 1 mile.

MONROE, ST. CLAIR, AND WASHINGTON COUNTIES.

Geologic maps of New Athens-Okawville quadrangles, showing structure contours on coal bed, E. W. Shaw, *U. S. Geol. Survey Geol. Folio 213* (1921). Scale, 1:62,500.

MONTGOMERY COUNTY

(See Madison County.)

Map showing structure of Mt. Olive Quadrangle, W. Lee, *Illinois Geol. Survey Bull. 31* (1915), Pl. 10; *ibid., Bull. 30* (1914), Fig. 3. Scale, 1:48,000.

Structure map of Nokomis-Ohlman area, G. F. Moulton, *Illinois Geol. Survey Rept. Investig. 6* (1925), Fig. 8.

MORGAN COUNTY

Structure map in the vicinity of Jacksonville, D. M. Collingwood, *Illinois Geol. Survey Bull. 44* (1923), Fig. 2. Cross section, Fig. 3.

Structure map of Jacksonville area, A. H. Bell, *Illinois Geol. Survey Petrol. 11* (September 3, 1927), Fig. 1. Scale, about $1\frac{3}{4}$ inches: 1 mile.

NORTHERN

Structure map of Longwall coal district in Bureau, LaSalle, Grundy, Putnam, Marshall, and parts of Will, Kankakee, and Livingston counties—contours on coal No. 2, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 10*, Pl. 1. In coöperation with U. S. Geol. Survey.

Structure map and cross section of northern Illinois, F. T. Thwaites, *Illinois Geol. Survey Rept. Investig. 13* (1927), Pls. 1–2.

OGLE AND LEE COUNTIES

Map showing structure on St. Peter sandstone in Dixon Quadrangle, R. S. Knappen, *Illinois Geol. Survey Bull. 49* (1926), Pl. 5. Scale, about $\frac{1}{2}$ inch: 1 mile.

PEORIA AND TAZEWELL COUNTIES

Map showing contours on coal beds in Peoria Quadrangle, J. A. Udden, *U. S. Geol. Survey Bull. 506* (1912), Pl. 2. Scale, 1:62,500.

PERRY COUNTY

Small map showing contours on coal No. 6 at Duquoin, Jon Udden, *Illinois Geol. Survey Bull. 14* (1909), Pl. 4.

Map showing contours on coal No. 6 in parts of Campbell, Coulterville, Pinckneyville, and Murphysboro quadrangles, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 31* (1927), Pl. 5. Scale, 1 inch: 1 mile.

Structure maps of Pinckneyville and Jamestown areas, A. H. Bell *et al.*, *Illinois Geol. Survey Illinois Petrol. 19* (April 11, 1931), Figs. 4–5.

PIKE COUNTY

Structure map of central and northern Pike County, *Illinois Geol. Survey Bull. 40* (1919), Pl. 4; structure sections, Pl. 9.

Map of crest of Pittsfield-Hadley anticline in Pike County with section, H. N. Coryell, *ibid.*, Pl. 6.

Map showing structure in central and northern Pike County, A. H. Bell, *Illinois Geol. Survey Petrol. 3* (July 24, 1926), Fig. 5.

POPE AND SALINE COUNTIES

Geologic cross sections in Pope and Saline counties, Albert D. Brokaw, *Illinois Geol. Survey Bull. 35*, Pl. 3. Scale, 2 inches: 1 mile.

RANDOLPH COUNTY

Geologic cross section, Schulines to Coulterville, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pl. 15; Tilden to Sparta, Pl. 16; coal contour map showing structure and development in Sparta field, Pl. 17.

Map of Bremen anticline, F. H. Kay, *Illinois Geol. Survey Bull. 33* (1916). Scale, 1½ inches: 1 mile.

Structure map of Sparta area in Randolph County, G. F. Moulton, *Illinois Geol. Survey Petrol. 1* (April 17, 1926), Pl. 1.

Map showing structure contours on coal No. 6 in parts of Baldwin and Coulterville quadrangles, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 31* (1927), Pl. 4. Scale, 1 inch: 1 mile.

RANDOLPH AND MARION COUNTIES

Stratigraphic section, from Randolph County northeast into Marion County, E. W. Shaw, *Illinois Geol. Survey Bull. 20* (1915), Pl. 4.

RANDOLPH, PERRY, AND JACKSON COUNTIES

Structure maps of Ava-Campbell Hill area, T. B. Root, *Illinois Geol. Survey Rept. Investig. No. 16* (1928), Pls. 2–3; cross sections of same area, Figs. 2–4.

ROCK ISLAND AND MERCER COUNTIES

Map showing structure contours on coal, T. E. Savage and J. A. Udden, *Illinois Geol. Survey Bull. 38* (1922), Pl. 2. Scale, 1:62,500.

SALINE COUNTY

Map showing contours on coal No. 6 in the vicinity of Harrisburg, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 19* (1919), Pl. 5.

SALINE AND GALLATIN COUNTIES

Map showing structure contours on coals 5 and 6, *ibid.*, Pls. 1, 4.

SALINE AND WILLIAMSON COUNTIES

Structure map of parts of Saline and Williamson counties, *ibid.*, *Rept. Investig. 2* (1925), Pl. 1; geologic section, Pl. 2.

SALINE, WILLIAMSON, POPE, AND JOHNSON COUNTIES

Map showing geologic structure in parts of Saline, Johnson, Pope, and Williamson counties, Albert D. Brokaw, *Illinois Geol. Survey Bull. 35*, Pl. 2. Scale, ¾ inch: 1 mile.

SANGAMON COUNTY

Structure map of Tallula and Springfield quadrangles, E. W. Shaw and T. E. Savage, *Illinois Geol. Survey Coal Mining Ser. Bull. 26* (1921). Also in *U. S. Geol. Survey Geol. Folio 188.*

Map showing structure in Springfield Quadrangle, T. E. Savage, *Illinois Geol. Survey Bull. 20* (1915), Pl. 11; stratigraphic sections, Pl. 12. Scale, 1 inch: 1 mile.

SANGAMON AND MENARD COUNTIES

Geologic maps of Tallula-Springfield quadrangles, showing structure contours on coal bed, E. W. Shaw and T. E. Savage, *U. S. Geol. Survey Geol. Folio 188* (1913). Scale, 1:62,500.

Map showing geologic structure of Springfield Quadrangle, T. E. Savage, *Illinois Geol. Survey Bull. 20* (1915), Pl. 11. Scale, 1 inch:1 mile.

Structure map of the Tallula and Springfield quadrangles, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 26* (1917), Pl. 8.

SCHUYLER, BROWN, ADAMS, AND HANCOCK COUNTIES

Map showing structure contours on coal No. 2, in parts of Schuyler, Brown, Adams, and Hancock counties, W. C. Morse and J. L. Rich, *Illinois Geol. Survey Bull. 31* (1915), Pl. 1. Scale, ⅝ inch:1 mile.

ST. CLAIR COUNTY

Map showing structure contours on coal No. 6 in parts of Waterloo and New Athens quadrangles, G. H. Cady, *Illinois Geol. Survey Coal Mining Investig. Bull. 31* (1927), Pl. 2; in parts of New Athens, Baldwin, and Coulterville quadrangles, Pl. 3. Scale, 1 inch:1 mile.

ST. CLAIR AND GALLATIN COUNTIES

Cross section, Belleville to Equality, Illinois, R. S. Blatchley, *Illinois Geol. Survey Bull. 16* (1910), Pl. 8.

ST. CLAIR AND WASHINGTON COUNTIES

Structure map of Morrison-Darmstadt area, G. F. Moulton, *Illinois Geol. Survey Rept. Investig. 6* (1925), Fig. 9. *Illinois Geol. Survey Petrol. 18* (November 2, 1929), Fig. 2.

Structure map of Dupo field, A. H. Bell, *Illinois Geol. Survey Petrol. 17* (March 2, 1929), Fig. 1; structure map of Waterloo and Dupo fields, Fig. 2.

SOUTHERN—MONROE, CLINTON, AND LAWRENCE COUNTIES

Section across southern Illinois, through Monroe, Clinton, and Lawrence counties, showing LaSalle anticline, R. S. Blatchley, *Illinois Geol. Survey Bull. 22* (1913), Pl. 1B.

SOUTHEASTERN

Stratigraphic section along axis of Bellair-Champaign uplift from Lawrence to Coles County (Lawrence, Crawford, Clark, and Coles counties). L. A. Mylius, *Illinois Geol. Survey Bull. 54* (1927), Pl. 2; structure section, Tuscola to Vermilion County, Indiana, Pl. 3. Scale, about 1 inch:4 miles.

Parts of Saline, Williamson, Pope, and Johnson counties, showing structure, A. D. Brokaw, *Illinois Geol. Survey Bull. 35* (1917), Pl. 2; cross section in Pope and Saline counties, Pl. 3.

SOUTHWESTERN

Map showing geologic structure in southwestern Illinois, especially Carlyle oil field in Clinton County. Contouring extends in Madison, Bond, Fayette, Marion, Clinton, St. Clair, Washington, Jefferson, Perry, and Randolph counties, E. W. Shaw, *Illinois Geol. Survey Bull. 20* (1915), Pl. 2. Scale, 1 inch:4 miles.

Stratigraphic section from Monroe County through Carlyle oil field in Clinton County, *ibid.*, Pls. 3, 5.

Map showing structure in southwestern Illinois, including Randolph, Perry, Monroe, St. Clair, Jefferson, and Marion counties, *ibid.*, Pl. 2; stratigraphic sections, Pls. 3, 4; structure section, Pl. 5.

Structure map of southwestern Illinois, showing contours on No. 6 coal, E. W. Shaw, *U. S. Geol. Survey Geol. Folio 213* (1921), Fig. 5. Scale, 1:62,500,

Structure map of southwestern Illinois, contours on No. 6 coal (Macoupin, Montgomery, Fayette, Shelby, parts of Christian and Sangamon, Marion, Randolph, St. Clair, Bond, Clinton, Perry, and Washington counties), F. H. Kay and K. D. White, *Illinois Geol. Survey Coal Mining Investig. Bull. 11*, Pl. 1. Scale, 1 inch:4 miles. In coöperation with U. S. Geol. Survey.

VERMILION COUNTY

Structure map of vicinity of Danville, contours on coal No. 6, F. H. Kay and K. D. White, *Illinois Geol. Survey Coal Mining Investig. Bull. 14* (1922), Pl. 2.

WABASH COUNTY

Structure map of Allendale field, J. L. Rich, *Illinois Geol. Survey Bull. 31* (1915), Pl. 4; cross section through field, Pl. 5. Scale, 4 inches:1 mile.

Map showing structure of Allendale area, G. F. Moulton, *Illinois Geol. Survey Rept. Investig. 7* (1925), Pl. 1; sections showing structure, Pls. 2–4. Also in *Oil and Gas Jour.* (February 4, 1926), p. 24.

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Structure map, R. V. Hennen and R. M. Gawthrop, *West Virginia Geol. Survey County Rept.* (1917). Scale, 1:62,500.

BROOKE COUNTY

Structure map, R. C. Tucker, *West Virginia Geol. Survey County Rept.* (1906). Scale, 1:62,500.

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JACKSON COUNTY

Structure map, C. E. Krebs, *West Virginia Geol. Survey County Rept.* (1911). Scale, 1:62,500.

KANAWHA COUNTY

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MCDOWELL COUNTY

Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1915). Scale, 1:62,500.

MARION COUNTY

Structure map, R. V. Hennen and D. B. Reger, *West Virginia Geol. Survey County Rept.* (1913). Scale, 1:62,500.

MARSHALL COUNTY

Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1909). Scale, 1:62,500.

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Structure map, C. E. Krebs, *West Virginia Geol. Survey County Rept.* (1911). Scale, 1:62,500.

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Structure map, C. E. Krebs, assisted by D. D. Teets, Jr., *West Virginia Geol. Survey County Rept.* (1916). Scale, 1:62,500.

Structure map, D. B. Reger and Paul H. Price, *West Virginia Geol. Survey County Rept.* (1925). Scale, 1:62,500.

MINERAL COUNTY

Structure map, D. B. Reger and R. C. Tucker, *West Virginia Geol. Survey County Rept.* (1924). Scale, 1:62,500.

MINGO COUNTY

Structure map, R. V. Hennen and D. B. Reger, *West Virginia Geol. Survey County Rept.* (1915). Scale, 1:62,500.

MONONGALIA COUNTY

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PUTNAM COUNTY

Structure map, C. E. Krebs, *West Virginia Geol. Survey County Rept.* (1911). Scale, 1:62,500.

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Structure map, west of New River, C. E. Krebs and D. D. Teets, Jr., *West Virginia Geol. Survey County Rept.* (1916). Scale, 1:62,500.

Structure map, D. B. Reger and Paul H. Price, *West Virginia Geol. Survey County Rept.* (1925). Scale, 1:62,500.

TAYLOR COUNTY

Structure map, R. V. Hennen and D. B. Reger, *West Virginia Geol. Survey County Rept.* (1913). Scale, 1:62,500.

TUCKER COUNTY

Structure map, D. B. Reger, *West Virginia Geol. Survey County Rept.* (1923). Scale, 1:62,500.

TYLER COUNTY

Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1909). Scale, 1:62,500.

UPSHUR COUNTY

Structure map, D. B. Reger, *West Virginia Geol. Survey County Rept.* (1918).

WAYNE COUNTY

Structure map, C. E. Krebs, *West Virginia Geol. Survey County Rept.* (1913). Scale, 1:62,500.

Structure map of part of county, W. C. Phalen, *U. S. Geol. Survey Geol. Folio 184* (1912). Scale, 1:125,000.

WEBSTER COUNTY

Structure map, D. B. Reger, *West Virginia Geol. Survey County Rept.* (1920).

WETZEL COUNTY

Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1908).

WOOD COUNTY

Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1910). Scale, 1:62,500.

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Structure map, R. V. Hennen, *West Virginia Geol. Survey County Rept.* (1915). Scale, 1:62,500.

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Topography of the pre-Cambrian surface in Nebraska, Kansas, and Missouri, F. T. Thwaites and J. V. Howell, *ibid.*, Fig. 227.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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GRAPHIC TREATMENT OF FOLDS IN THREE DIMENSIONS[1]

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ABSTRACT

A graphic construction of folded beds included between the end points of a traverse, along which both the dip and strike change, is presented. The construction includes the determination of the thickness of beds between two selected strike and dip readings, the direction of the axis, and the pitch of the fold. A method for the determination of the accuracy of the strike and dip readings, provided the folding is concentric, is also included. If the folding is similar and the strike and dip readings are accurate, an approximation of the amount of thickening or thinning is afforded.

INTRODUCTION

The Busk method[3] of measuring the thickness of a series of concentrically folded beds included between the end points of a traverse is limited in application to vertical sections along the true dip. It deals with changing dip but constant strike and is 2-dimensional. If, however, both the strike and dip change along the traverse, the problem becomes 3-dimensional and, although a very common one, has not previously been worked out, as far as the writer can learn.

A traverse run across the axis of a plunging anticline or syncline shows progressively changing strikes and dips (Fig. 1) and supplies typical data for the construction to be described. Methods are developed for the following determinations: (1) nature of folding—similar or concentric; (2) if similar, the approximate degree of thickening or thinning; (3) if concentric, the curvature of the beds, and the thickness between two chosen strike and dip readings; (4) the direction and pitch of the axis of the fold; (5) any errors in the strike and dip readings.

PRINCIPLES

The only section in which the true thickness and curvature of concentrically folded beds can be measured is one perpendicular to the axis of the fold. The entire construction has for its objective the establishment of this plane in true dimensional view. The direction of the

[1] Manuscript received, December 13, 1937.

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[3] H. G. Busk, "Earth Flexures," *Cambridge Geological Series*, Cambridge University Press (1929), pp. 13-19.

axis must first be determined in order that a plane perpendicular to it be constructed. If a series of beds is folded concentrically there is one direction in which a straight line lies in the plane of bedding.[4] This direction is that of the axis and may be compared with a line in a cylindrical surface parallel with the axis. Hence, each of the planes represented by the strike and dip readings, such as *A*, *B*, and *C* (Fig. 1), must have one parallel direction. This is the direction of their lines of intersection and is the direction of the axis. Should the line of intersection of two of the planes, *A* and *B*, be not quite parallel with

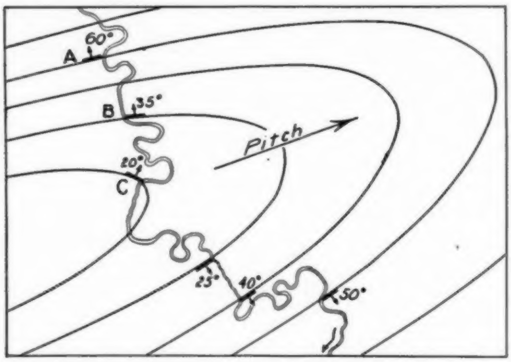


FIG. 1.—Diagram showing dip and strike change along a traverse across the axis of a plunging anticline or syncline.

the intersection of one of these and a third, *B* and *C*, several possibilities should be considered: (1) the folding may not be perfectly concentric—some thickening or thinning of the beds may have occurred; (2) the formation may have original depositional irregularities in thickness, that is, convergence; (3) one of the strike and dip readings may not be accurate. The amount that a certain strike or dip reading, *C*, must be corrected, in order to conform to the other data, may be obtained by assuming an intersection of planes *B* and *C* parallel with the direction of intersection of planes *A* and *B*. By working the steps of the construction backward for the determination of the intersection of the two planes, *B* and *C*, from the assumed intersection, a new or corrected dip (or strike) reading for *C* may be found. This figure conforms with the other data, provided the folding is truly concentric. Should, however, the dip reading of *C* be rechecked in the field and found accurate, the beds must thicken or thin, and the

[4] An exception is the limiting case of a quaquaversal fold.

amount may be estimated from the divergence of the recorded dip reading from the corrected one.

With the direction of the axis determined, a plane perpendicular to it is constructed. This will be called plane *D*. The strike and dip readings may now be referred to a new plane, *E*, perpendicular to *D*, dipping in the same direction and the same amount as the axis, and consequently defined by the direction of the axis as the dip and a horizontal line perpendicular to the axial direction as the strike. The intersections of the planes *A*, *B*, and *C* with *E* will all be parallel and will also parallel the direction of the axis. The dips of planes *A*, *B*, and *C* may be found in plane *D*, which is the true cross section to *E*, by determining their intersections with *D*.

Thus, the original strike and dip readings have been resolved into a plane where they have parallel strikes but new dips; and the new dips have been determined. Since the strikes are parallel, the points along the traverse not in a straight line and having different elevations may be projected parallel with the new reference plane, *E*, to a true cross section which is then ready for the Busk construction for the determination of thickness and curvature.

CONSTRUCTION

The basic data with which to present the solution of the problem have been chosen as illustrated in Figure 2. Dips of 70°, 50°, and 30°, and elevations of 300 feet, 500 feet, and zero feet, respectively, are assumed. The strike shifts through approximately 45°.

Step one.—If the fold of Figure 2 is concentric, then there is a line common in direction to each of the three planes of the strike and dip readings, *A*, *B*, and *C*, and when found, this is the direction of the axis. The angle it makes with a horizontal plane is the pitch.

The only line common to the plane of *A*[5] and the plane of *B* is the line of intersection of the two planes. Likewise the only line common to the planes of *B* and *C* is their line of intersection. Since *B* has only one line direction parallel with *A* and only one parallel with *C*, it is necessary that these two be parallel in order that *A* and *B* have a common direction with *C*.

In order to find the line of intersection of planes *A* and *B*, proceed in construction as follows. Select horizontal upper and lower reference planes at a distance apart convenient for accurate drafting. It is not necessary to take into consideration the different elevations of the three points of strike and dip readings, *A*, *B*, and *C*. Since only the

[5] The large letters, *A*, *B*, and *C* (Fig. 2) are used to refer to the location of the different strike and dip readings and also to the planes defined by these readings.

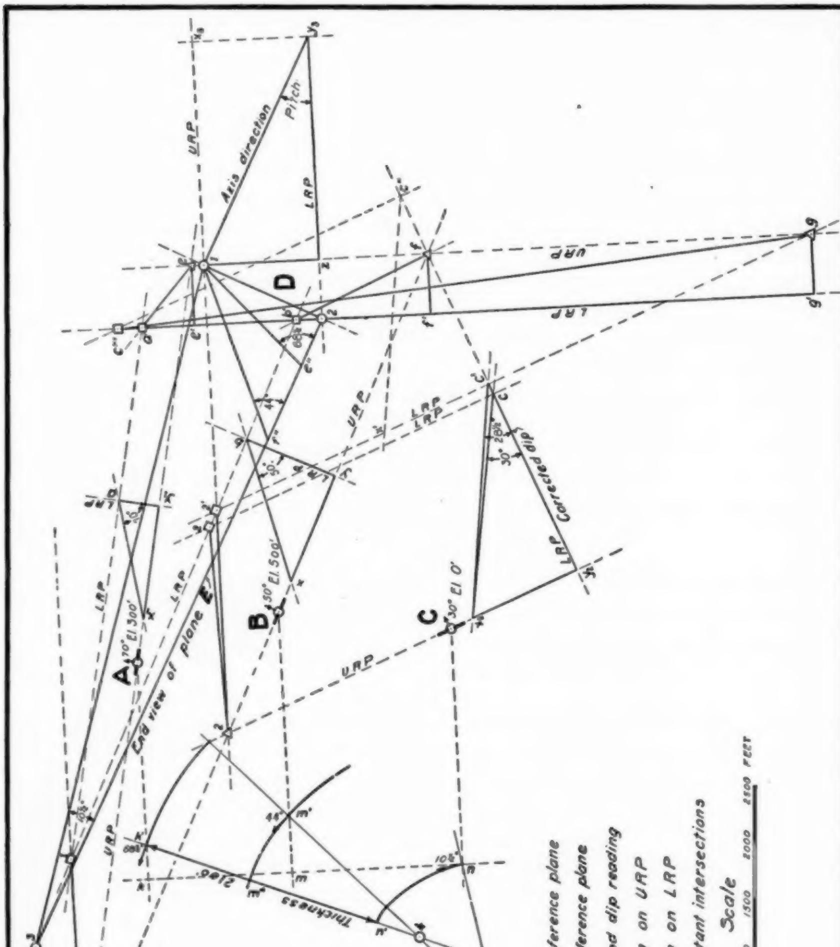


FIG. 2.—Diagram showing basic data used in graphic treatment of folds in three dimensions to determine curvature of fold and thickness of beds.

direction of the axis is to be determined it makes no difference what the locations (vertical or horizontal) of the intersecting planes are in this step of the construction. So long as the planes remain oriented as required by the strike and dip readings, their intersections have the same direction. If the construction runs off the paper the horizontal location of the plane concerned may be shifted.

Extend the lines of strike and lay off the chosen distance between the reference planes on each of these strike lines. For plane *B* it is the line $x\ y$. (The distance between the reference planes is labeled x_1y_1, x_2y_2, and x_3y_3 in all other places of the construction.) Through x draw a line making an angle of 50° with the lower reference plane. A triangle, x, y, b is thus formed with the hypotenuse representing plane *B*. If a line be drawn through b in the lower reference plane parallel with the strike, the line of intersection of plane *B* with the lower reference plane is found. The strike line first drawn is the line of intersection of plane *B* with the upper reference plane. Likewise by construction of triangle $x_1y_1\ a$ for plane *A* with the hypotenuse dipping 70°, the intersections of plane *A* with the upper and lower reference planes are found.

The intersection of plane *A* with the upper reference plane meets the intersection of plane *B* with the upper reference plane at △1. The lower reference plane intersections meet at ⊡1. A line connecting △1 and ⊡1 is the horizontal projection of the intersection of planes *A* and *B*. It is the only line they have in common and is the direction of pitch of the fold.

In the same manner the intersection of planes *B* and *C* is found, constructing the triangle x_2y_2c with the given dip of 30°. The line of intersection of planes *B* and *C* is △2 ⊡2. But this line, which is likewise the direction of the axis, is not quite parallel with the axis direction △1 ⊡1. The amount that a certain strike or dip reading must be corrected in order to conform to the other data may be obtained as follows. If there is reason to suppose that the dip reading for *C* was inaccurate, the correct dip reading is found by drawing a line through △2 parallel with △1 ⊡1 and intersecting ⊡2b at ⊡2′. △2 ⊡2′ is the line of intersection, as it should be provided all other readings are accurate and the folding is perfectly concentric. Draw ⊡2′ c' parallel with ⊡2 c. The correct hypotenuse of the triangle x_2y_2c is thus obtained, x_2c', and the corrected dip is measured as $28\frac{1}{2}$°. If the dip reading is rechecked and found to be correct, the error of $1\frac{1}{2}$° may be taken as the local divergence from parallelism of the bedding planes bounding the top and bottom of the formation. This is an approximate expression of the amount of thinning or thickening.

Step two.—With the axial direction determined, a plane perpendicular to this direction should be constructed upon which the true thickness of the beds can be measured. This plane is called *D*.

To do this, extend the horizontal projection of the direction of the axis, $\triangle 2 \boxdot 2'$, to the right. Through a convenient point on this line, $\odot 1$, draw a normal, $\odot 1 \triangle g$. This line is the intersection of plane *D* with the upper reference plane. To find its intersection with the lower reference plane lay off $\odot 1\, x_3$ equal to $\triangle 2 \boxdot 2'$, and x_3y_3 perpendicular to $\odot 1\, x_3$ and equal to the chosen distance between the upper and lower reference planes. The line $\odot 1\, y_3$ becomes the true axis direction when the triangle $\odot 1\, x_3y_3$ is rotated about $\odot 1\, x_3$ down to a vertical position. The angle $\odot 1\, y_3z$ is the true angle of pitch.

Plane *D* is constructed by drawing a normal, $\odot 1 \odot 2$, to $\odot 1\, y_3$ through $\odot 1$. The normal intersects the lower reference plane at $\odot 2$, and determines the intersection of plane *D* with the lower reference plane, $\odot 2\, g'$. The plane *D* is thus established.

Step three.—If a plane *E* be determined by the axis direction as the dip and a horizontal line normal to the axis direction as the strike, then the three planes, *A*, *B*, and *C*, have a common direction of intersection with *E*. If, now, the plane *E* is taken as a new reference plane for strike and dip readings, the three planes, *A*, *B*, and *C*, have parallel strikes. This strike direction in horizontal projection is of course, the axial direction $\triangle 2 \boxdot 2' \odot 1$. In addition to the strike of *A*, *B*, and *C* in plane *E*, their dips referred to *E* must be determined. Since plane *D* is a true cross section of beds referred to plane *E*, then the intersections of planes *A*, *B*, and *C*, with plane *D* yield the desired dips.

The lower reference plane intersections through *a*, *b*, and c' are extended to meet the lower reference plane intersection of *D* ($\odot 2\, g'$) and are a', b', and c''', respectively. In order to conserve space the triangle x_2y_2c' may be shifted to x', c', c'' and c'' projected to c''' on $\odot 2\, g'$. This is permissible because it is the new direction of dip that is being sought and not the location of a plane. Likewise the upper reference plane intersections may be projected to *e*, *f*, and *g*. The lines connecting a' and *e*, b' and *f*, and c''' and *g*, are the horizontal projections of the intersections of planes *A*, *B*, and *C*, respectively, with *D*. The angles between these intersection lines and plane *E* measured in *D* give the new dip angles desired.

Step four.—In order to make a Busk construction of the fold represented by the three dip readings, normal to the axis direction and to the plane *E*, it is necessary to determine the actual angle of the new dips in plane *D*. As constructed so far only the horizontal projections of the dip lines are established. The new dip angles may be determined by drawing a line through $\odot 2$ normal to the plane *D*. This line, $\odot 2\, s$, is the end view of plane *E*, and line $\odot 1 \odot 2$ the end view of plane *D*, for

example, the intersections of a vertical plane with E and D, respectively, along the direction of pitch. The full dimensional view of triangle $a'e\,e'$ becomes $\odot 1 \odot 2\, e''$, when $\odot 2e''$ is laid off on $\odot 2 \odot 3$ equal to $a'e'$. By measuring with a protractor the new dip of $68\frac{1}{2}°$ is obtained. This is the dip the plane A makes with the new reference plane E. Likewise the full dimensional view of triangle $b'ff'$ becomes $\odot 1 \odot 2\, f''$ ($\odot 2f''=b'f'$) with a measured dip of 44°. Also triangle $c'''g\,g'$ becomes $\odot 1 \odot 2 \odot 3$, and the new dip angle is $10\frac{1}{2}°$.

Thus far a new reference plane for the three strike and dip readings (A, B, and C) has been found in which their strikes are parallel. Their dips related to the new reference plane have also been determined.

Step five.—It remains now to construct a cross section perpendicular to plane E, to project the points of original dip readings to it parallel with E, and to proceed simply with the construction of Busk. Draw a line $k\,n$ perpendicular to the axis direction $\triangle 2\, \boxdot 2'$. Project to it the points of original dip readings. Consider the line $k\,n$ to be the intersection of plane E with a plane normal to the axis direction. (The plane perpendicular to E is parallel with D.) Lay off $k\,k'$ equal to the elevation of point A; likewise mm' equal to the elevation of point B. Point C has a zero elevation and hence is on the line $k\,n$ at n. The same vertical scale as horizontal scale must be used.

From k' construct a normal to the dip of $68\frac{1}{2}°$; from m' construct a normal to the dip of 44°; from n construct a normal to the dip of $10\frac{1}{2}°$. Normals k' and m' intersect at $\odot 4$ and normals m' and n at $\odot 5$. Using these intersections as centers and the normals as radii, construct the arcs as shown and the true thickness of the beds included between points A and C is $k'n'$. The thickness between points A and B is $k'm'$ and the thickness between points B and C is $m''\,n'$.

The curvature of the beds determined by the three strike and dip readings, A, B, and C, is established at the same time. If more readings along the traverse as shown in Figure 1 are referred to plane E and projected to the cross section, then the anticline and its axial plane can be constructed.

CONCLUSIONS

Given two or more changing strike and dip readings along a traverse, the curvature of the fold and the thickness of the beds included between any or all of the readings may be determined, and the direction of the axis and the pitch of the fold may be found. The solution holds good only for beds that are folded concentrically. An approximation of the amount of thickening or thinning of the beds may be obtained if similar folding has occurred and if the strike and dip readings are correct. If any are suspected of being inaccurate, the amount may be determined, assuming perfect concentric folding.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 4 (APRIL, 1938), PP. 490-506, 3 FIGS.

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

GROUND WATER
BY C. F. TOLMAN[1]

REVIEW BY O. E. MEINZER[2]
Washington, D. C.

**Ground Water*. By C. F. Tolman. 593 pp., 189 figs. 6×9 inches. Cloth. McGraw-Hill Book Company, New York (1937). Price, $6.00.

Professor Tolman's volume of 593 pages, with 189 illustrations, fills a need that has long been recognized for a comprehensive textbook in this country on the subject of ground water. It should be of distinct value in making available the results of the large amount of scientific study and investigation that has been given to this important subject, and should speed the day when it will be included among the essential courses in the departments of geology in the large universities and institutes of technology. I am personally greatly gratified that Professor Tolman has drawn freely from the results of the work of the Division of Ground Water of the Geological Survey, to which he has made such fair and generous reference. It is also gratifying that he adopted very largely the terminology that has long been in use in the Geological Survey, because such a conservative policy in this textbook will avoid much confusion.

As the author is an experienced geologist and a professor of geology, the book has a sound geological basis. However, it is distinctly a treatise on hydrology, emphasizing the occurrence and dynamics of ground water and the quantitative methods. It presupposes a general but not a specialized knowledge of physics and geology.

The introductory chapter gives somewhat of the historical background of ground-water development and theory, calls attention to the popular superstitions and misinformation regarding ground water, and emphasizes its economic importance. It gives an interesting description of the elaborate tunnels that have been dug in Persia to obtain water supplies.

Chapter 2 is an elementary outline of the subject of ground water, designed especially for the benefit of lawyers who are concerned with water rights. Chapter 3 is a brief treatment of rainfall, run-off, evaporation, and transpiration, with special reference to ground water.

Chapter 4 describes the primary and secondary openings in the rocks that serve as water reservoirs, and outlines the hydrologic properties of rocks, such as porosity, specific yield, specific retention, specific absorption and permeability. The term specific absorption is introduced as differing from

[1] Manuscript received, March 11, 1938.

[2] United States Geological Survey.

specific yield in formations that undergo appreciable compaction as a result of pumping.

Chapter 5 is an interesting discussion of the soil, with special reference to its capacity to absorb water and permit its movement to the water table. The statement is made that geologists have neither recognized and described the important characteristics of the soil, nor have they made important contributions to soil science in recent years. This indictment of the geologists is doubtless in general deserved but perhaps does not quite do justice to the few geologists who are keen students of the soil. The distinction is made between percolation and seepage, percolation being the movement of the water where the material is saturated, whether in the zone of saturation or temporarily in the zone of aeration, and seepage being the downward movement of water by gravity in the unsaturated parts of the zone of aeration.

Chapter 6 relates essentially to the difficult subject of the occurrence and movement of the water in the zone of aeration, and the operation of molecular and other forces. The classifications made and the terms used are doubtless only partly acceptable to the different students of soil moisture. The chapter ends with a brief discussion of crops that extend their roots into the capillary fringe, above the water table.

Chapter 7 distinguishes between influent and effluent seepage, and discusses influent seepage from rainfall and streams. It also discusses rather fully the artificial recharge of ground-water reservoirs by water-spreading and other means, which is a subject of great current interest.

Chapter 8, of which J. F. Poland is a joint author, treats of the movement of the water in the zone of saturation, the permeability of water-bearing materials, and the laboratory and field methods of determining permeability. It distinguishes clearly between the ordinary movement of ground water, which is laminar flow, obeying Darcy's law, and the exceptional, rapid movement through large openings, which is turbulent flow and does not obey Darcy's law. The term percolation is restricted to the laminar flow. This chapter makes a valuable contribution in dispelling the fiction, created by Daniell's textbook on physics and Van Hise's treatise on metamorphism, that there is a precise and very low limit in the size of openings that permit laminar flow. The chapter states:

> Daniell defines capillary tubes as those in which flow of water follows Poiseuille's law [Darcy's law]. He states categorically that "for water (a capillary tube) is a tube under 1/50th of an inch in diameter." The idea that there is a limiting size of tube which determines the type of flow is incorrect. *Laminar flow takes place in tubes of any size provided velocity is sufficiently slow.*

It is shown that the misconception is in disregard of the earlier work done by Osborne Reynolds and is disproved by recent experiments by Poland and others. Reference is also made to the recent work of Fishel which shows that Darcy's law holds for very slow percolation under extremely low hydraulic gradients. Thus Darcy's law is established for a wide range in the movement of ground water—the range commonly found under natural conditions. The important concept of hydraulic gradient is unfortunately not adequately explained in the text; in the glossary it is defined as "a profile showing the static level of water at all points on the profile," with a further statement that is no more enlightening.

Chapter 9 relates to the water table in granular permeable material, and

the relation of fresh to salt water (the Ghyben Badon or Herzberg principle). It also includes valuable discussions of geophysical methods by J. J. Jakosky and C. A. Heiland. The water table has long been a favorite subject of discussion. Tolman's concept of it does not appear quite clear, as he accepts my concept that the water table is at the bottom of the capillary fringe,[3] and yet he insists that it is a "physical surface." I appreciate the inclusion in his book (p. 224) of my personal communication, which is as follows.

> My concept of the water table is that it is a precise surface that is the locus of the static head of the unconfined water at the top of the zone of saturation—not essentially a physical water surface.

If the "physical surface" mentioned by Tolman is the contact surface between water and air it is obviously a very irregular surface passing through the capillary fringe and not indicating the static head of the unconfined water.

Chapter 10 discusses water in fractures and solution openings, including limestone and lava rocks. It discusses the relation of solution openings in limestone to the water table and the origin of openings that occur below the water table.

Chapters 11 and 12 relate essentially to artesian conditions, including rather detailed discussion of the geologic structure of artesian systems of different kinds—especially of the alluvial cones and fans. The term artesian is used as defined in *Water-Supply Paper 494*, to designate water with a head higher than that of the water at the water table. This definition recognizes the important distinction between a confining system that tends to hold water in from one that tends to hold water out. However, the term artesian has been used in so many different ways that it is difficult to restrict it to any specific meaning. The term "confined water" is used in this book to designate water in aquifers not in hydraulic connection with overlying water bodies except at the "fountain head," regardless of the position of the water level in the wells. The unconfined water is called "free water," although it is recognized that this term is often used for all water that is not under the control of molecular forces. As a matter of fact the water in the zone of saturation is so generally influenced by the texture and structure of the rocks that nearly all the water, even that which is only a short distance below the water table, has a head that is somewhat higher or lower than that indicated by the water table. Doubtless, however, it is a valuable general distinction that should be recognized with appropriate terms.

Since attention was called some years ago to the series of hydrologic phenomena that indicate not only compressibility but also elasticity of artesian aquifers,[4] that subject has assumed large importance with respect to both water and oil. The theory has, however, been persistently misunderstood by many geologists. The treatment of this subject in Chapter 11 should be helpful in cultivating a correct understanding of the theory and its significance.

Figures 11 and 13 and a statement in the second paragraph on page 59 may lead the reader to believe that the static head or pressure surface of an artesian aquifer may be determined by observing the height to which the water will spurt upward from a flowing well when a vertically discharging

[3] *U. S. Geol. Survey Water-Supply Paper 494*, pp. 21 and 22.

[4] *U. S. Geol. Survey Water-Supply Paper 520 e* (1925); *Econ. Geol.*, Vol. 23 (1928), pp. 263–91.

valve is opened. This idea is further suggested by the erroneous statement (page 318) that the large flow of a well in the Roswell basin was obtained with a head of only 5 feet, which was the height to which the water issued above a 12½-inch casing. Actually the "shut-in" head of the well was reported as 72 feet with reference to the land surface.[5] The conditions under which wells discharge by natural flow, often with large loss of pressure head through friction, are not entirely comparable to the case of a simple orifice described in the textbooks on hydraulics. In many wells the height to which the jet rises is far short of the true static level, which can be determined only by reading a pressure gage on a closed well or by observing the level to which the water will rise in a well that is tightly cased to a height sufficient to prevent any overflow. It may be noted that published reports lack adequate discussion of the hydraulic principles governing the discharge of water from flowing wells. It is perhaps for this reason that Tolman, in the definitions in the glossary, fails to apply the terms drawdown and specific capacity to flowing wells.

Chapter 13 gives a brief discussion of the hydraulics of wells, distinguishing between water-table wells and confined-water wells. Reference is made to the formula, published in the textbook by Turneaure and Russell, for determining the discharge of wells in areas of known permeability. This formula involves large R, or the distance from the pumped well at which the drawdown of the water level or pressure surface is inappreciable. As the distance R increases with the period of pumping and is quite indefinite, this formula has not proved to be very useful. This chapter could doubtless have been strengthened by a more thorough discussion of the subject, including the application of the Thiem and Theis methods to the discharge of wells in areas where the permeability is known. The chapter ends with a general description of well-drilling methods which is fairly comprehensive but omits the jetting method.

Chapter 14 contains a concise discussion of the occurrence, movement, and accumulation of "oil-field fluids" and the dynamics of these fluids under production. This discussion should be especially helpful to those students of ground water who are not familiar with the distinctive features of the physics of natural oil and gas. There is also a brief discussion of hydrologic data of interest to petroleum geologists and engineers.

Chapter 15 treats the entire subject of springs. Reference is made to the classifications of springs by Keilhack and by Bryan as the two best general classifications, and especial use is made of that of Bryan.

Chapter 16 is entitled "The Ground-Water Inventory." It outlines the methods of determining intake, discharge, and safe yield, largely as developed by the Geological Survey. The important subject of specific yield might well have been given fuller treatment either in this chapter or elsewhere in the book.

The last chapter (No. 17) relates to the ground-water provinces of the United States and constitutes a brief description of the ground-water conditions throughout the country, including Hawaii (by R. G. Sohlberg). The map of the ground-water provinces as given in *Water-Supply Paper 489* (Pl. 31) is reproduced without change, but there is an additional map in which much needed changes are made for the Pacific Coast region. The "Columbia Plateau lava province" is enlarged toward the west and south, and two new provinces are created, namely, the "Great Valley of California province,"

[5] *U. S. Geol. Survey Water-Supply Paper 619*, Well 614, p. 315.

and the "Coast Ranges of Central and Southern California province." This leaves a rather heterogeneous "Northern Coast Ranges province"—the shrunken remnant of my unsatisfactory "Pacific Mountain province."

The book ends with a glossary, a table of hydraulic conversion factors, and an index. A good bibliography is appended to each chapter.

GEOPHYSICAL SURVEY OF THE REICH AS BACKGROUND FOR PROSPECTING FOR MINERAL DEPOSITS

BY O. BARSCH

THE SUBSURFACE OF SCHLESWIG-HOLSTEIN IN LIGHT OF SEISMIC REFRACTION SURVEYS

BY H. REICH

REVIEW BY WALTER KAUENHOWEN[1,2]
Hamburg, Germany

"Die geophysikalische Reichsaufnahme als Grundlage für die Erschliessung neuer Lagerstätten" (Geophysical Survey of the Reich as Background for Prospecting for Mineral Deposits). By O. BARSCH. *Oel und Kohle* (Berlin SW 68), Vol. 12, No. 45 (December 1, 1936), pp. 1035–39.

"Der Untergrund von Schleswig-Holstein nach den Ergebnissen seismischer Refraktionsmessungen" (The Subsurface of Schleswig-Holstein in Light of Seismic Refraction Surveys). By H. REICH. *Pumpen- und Brunnenbau, Bohrtechnik* (Berlin SW 68), Vol. 33, No. 24 (November 26, 1937), pp. 763–69.

Since 1934 the German Government has used substantial funds for exploring wide areas of Germany by geophysical reconnaissance surveys. The purpose of this work is to facilitate the prospecting for mineral resources, and especially for oil.

These two publications are of great general interest, because through them for the first time the preliminary results of these investigations are being made public. The maps accompanying these papers clearly demonstrate the tremendous progress achieved during the last few years in determining the subsurface structural conditions of the North German Plains, especially within the provinces of Hannover and Schleswig-Holstein.

O. Barsch, director of the Government's geophysical survey, reviews in his paper the problems of this institute, the first task of which is a rapid reconnaissance of the major structural features by various geophysical methods. The detailing of structures thus discovered is being left to the initiative of private individuals and companies.

The preliminary results found in Hannover and Schleswig-Holstein by

[1] Manuscript received, February 8, 1938.

[2] Deutsche Vacuum Oel A. G.

means of torsion-balance and gravimeter measurements, are shown on the general map represented in Figure 1. This map is of special interest to the petroleum geologist because it also represents the latest published map of the salt plugs of northwestern Germany. Until the end of 1936 more than 35 new salt plugs were discovered in this area by the Government's geophysical survey. For the American reader the great progress in the investigation of this area is most clearly shown, if he compares the map by Barsch(Fig. 1) with the map of the German salt-plug province published by J. Brian Eby.[3] Figure 1 also shows oil fields on the flanks of salt plugs. Among the fields is Gifhorn, a recent discovery. The map also clearly indicates the salt plug of Neuengamme near Hamburg, not far from the old gas well whose subsequent testing resulted in the development of an oil field. The regional uplifts and the distribution of basins are also well indicated by the trend of the isogams.

The larger scale isogam map of Schleswig-Holstein published by Barsch (Fig. 2) is of special interest, because it changes completely the previous picture constructed with the very scanty evidence then available about the distribution of gravity within this province. The map also gives the gravimeter stations and the values observed. From these data it appears that a great regional gravity maximum trends from the vicinity of the Heide oil field northeasterly toward the Flensburg Foehrde. A second gravity maximum lies in the vicinity of Kiel. The geological interpretation of these maxima is not easy.

A comparison of this gravimetric map with the seismic map published by H. Reich (Fig. 3) brings out a marked dissimilarity, which suggests that the gravitational effects originate in much greater depths, a much lower "floor," than the seismic effects.

The seismic results of the Government's geophysical survey of Schleswig-Holstein, published for the first time by H. Reich (Fig. 3), may likewise be called revolutionary.

In a strict sense this map does not represent an ordinary contour map but a map of equal times of arrival of seismic waves, that is, of the seconds needed by the seismic energy to arrive at a distance of 4 kilometers from the shot point. The times of arrival were determined by refraction fan shooting and were checked by time-distance profiles.

The depth figures of the map represent approximately the depth of the first bed with a velocity higher than 3,000 meters per second. This bed can be of Upper Cretaceous, Upper Permian (Zechstein), or Lower Permian (Rotliegendes) age. The map, therefore, represents also at least approximately a contour map of the pre-Tertiary surface.

Based on the very scanty outcrops of pre-Tertiary rocks in Schleswig-Holstein geologists previously assumed a northwestern structural trend in the subsurface of this province and have assumed a northwesterly arrangement of salt plugs within the Lower Elbe area. The map (Fig. 3), however, shows clearly that this is not the fact, the strike of the main structural features of Schleswig-Holstein being north-northeast and the salt plugs on the south of the Lower Elbe being scattered irregularly.

A very characteristic feature revealed by this work is the existence of at least four north-northeast trending, horst-like ridges, each of which is approximately 50 kilometers long and 5 kilometers wide. The cores of these

[3] *Oil Weekly*, Vol. 72, No. 8 (February 5, 1934).

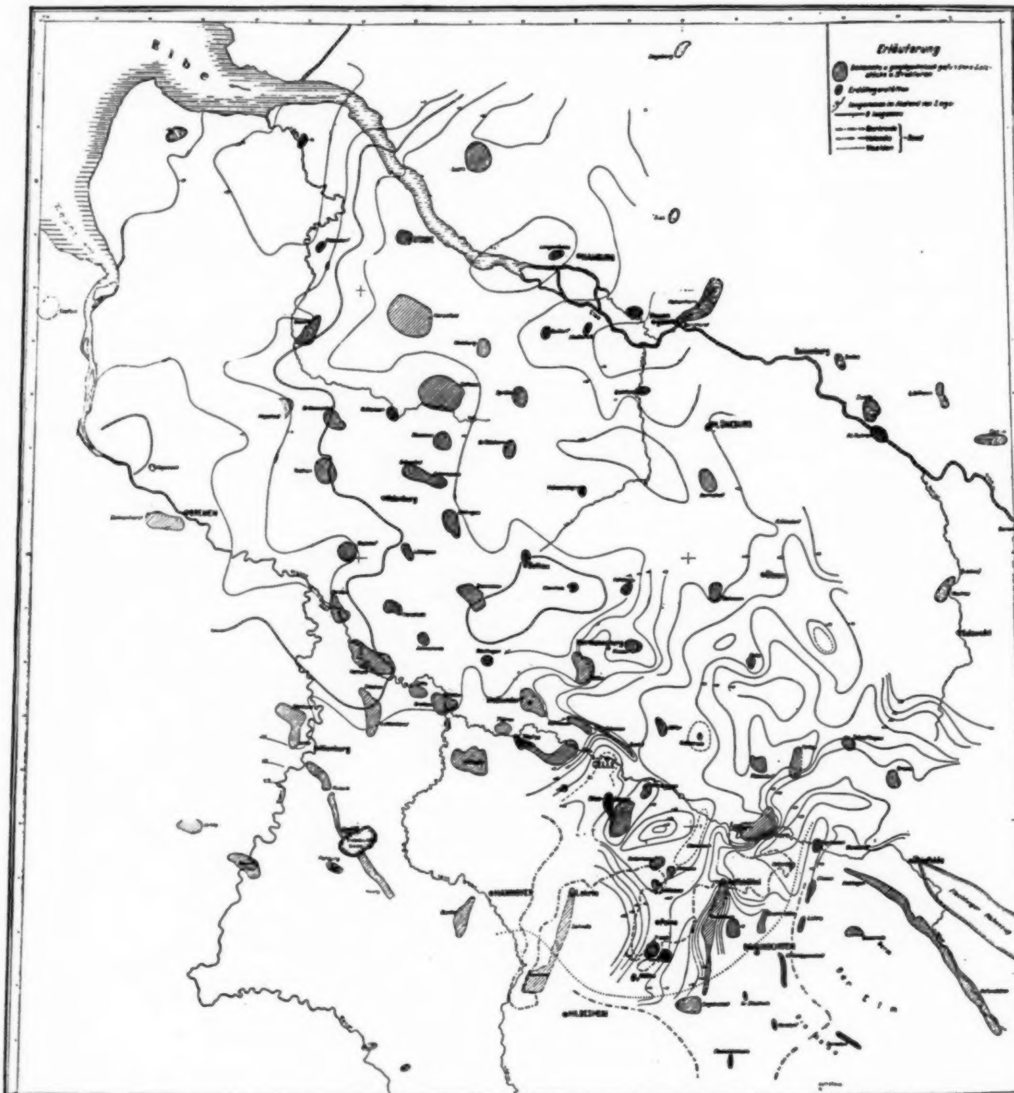


FIG. 1.—Gravimeter map of middle and north Hannover. Areas shaded with diagonal lines indicate known salt domes. Solid black areas indicate oil pools. Contour interval, 2 milligal.

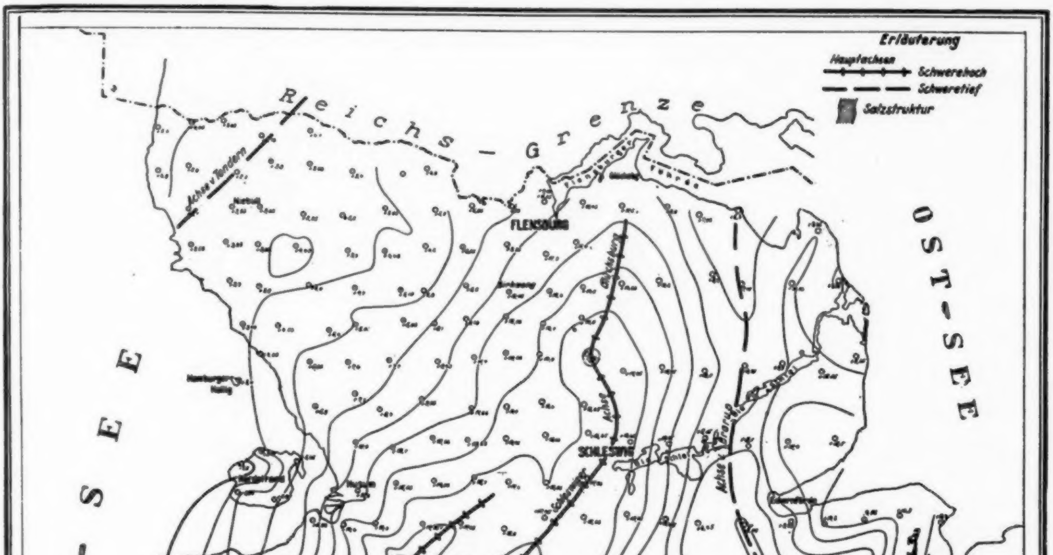
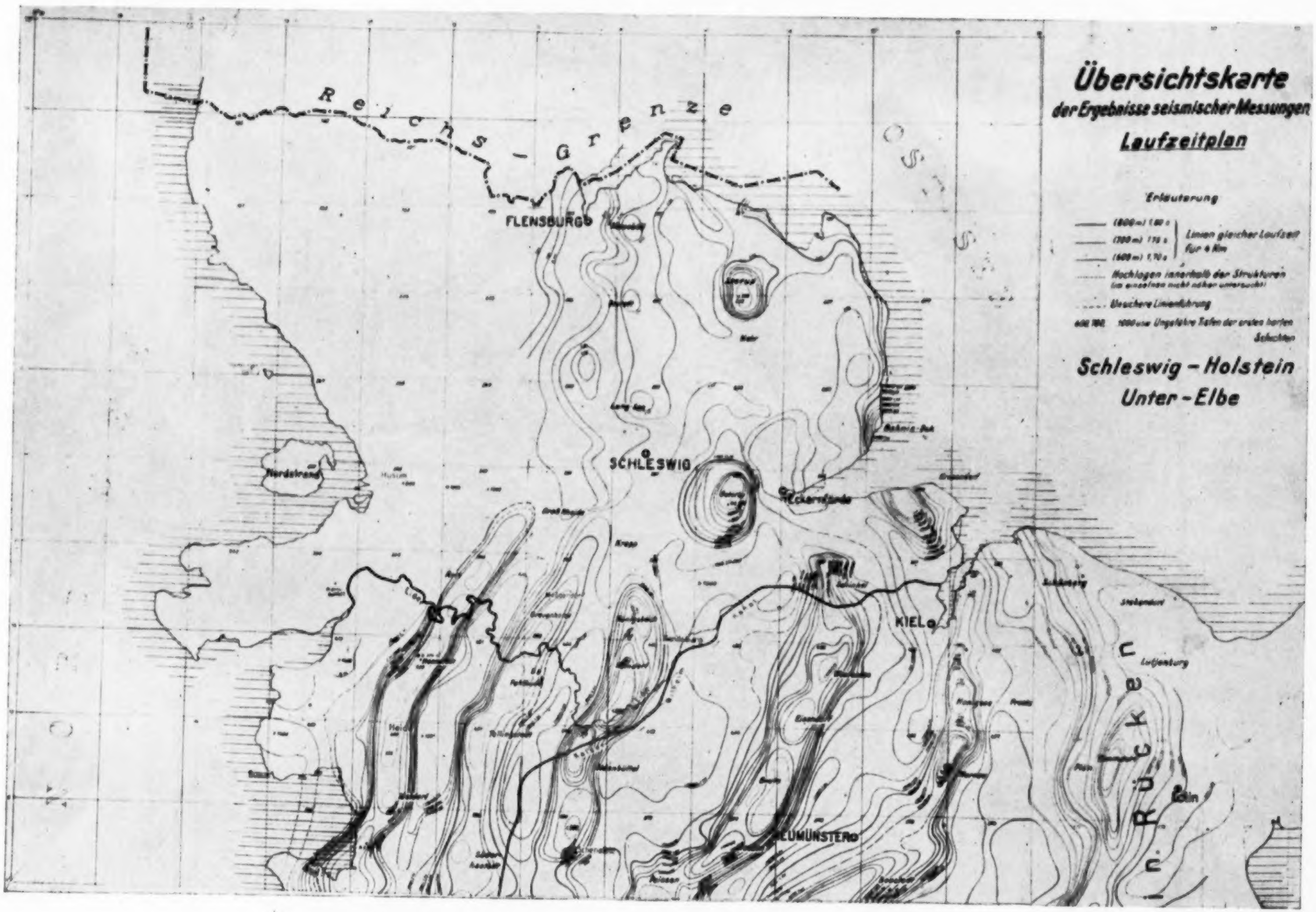


FIG. 2.—Gravity anomalies in Schleswig-Holstein, 1934–36. Gravity-high axes indicated by crossed lines. Gravity-low axes indicated by heavy broken lines. Diagonal lines indicate salt structure. Contour interval, 2 milligal.



Übersichtskarte
der Ergebnisse seismischer Messungen
Laufzeitplan
Erläuterung
Linien gleicher Laufzeit für 4 km
Hochlagen innerhalb der Strukturen
Unsichere Linienführung
Schleswig - Holstein
Unter - Elbe
Reichs - Grenze
FLENSBURG
SCHLESWIG
KIEL
Rücken

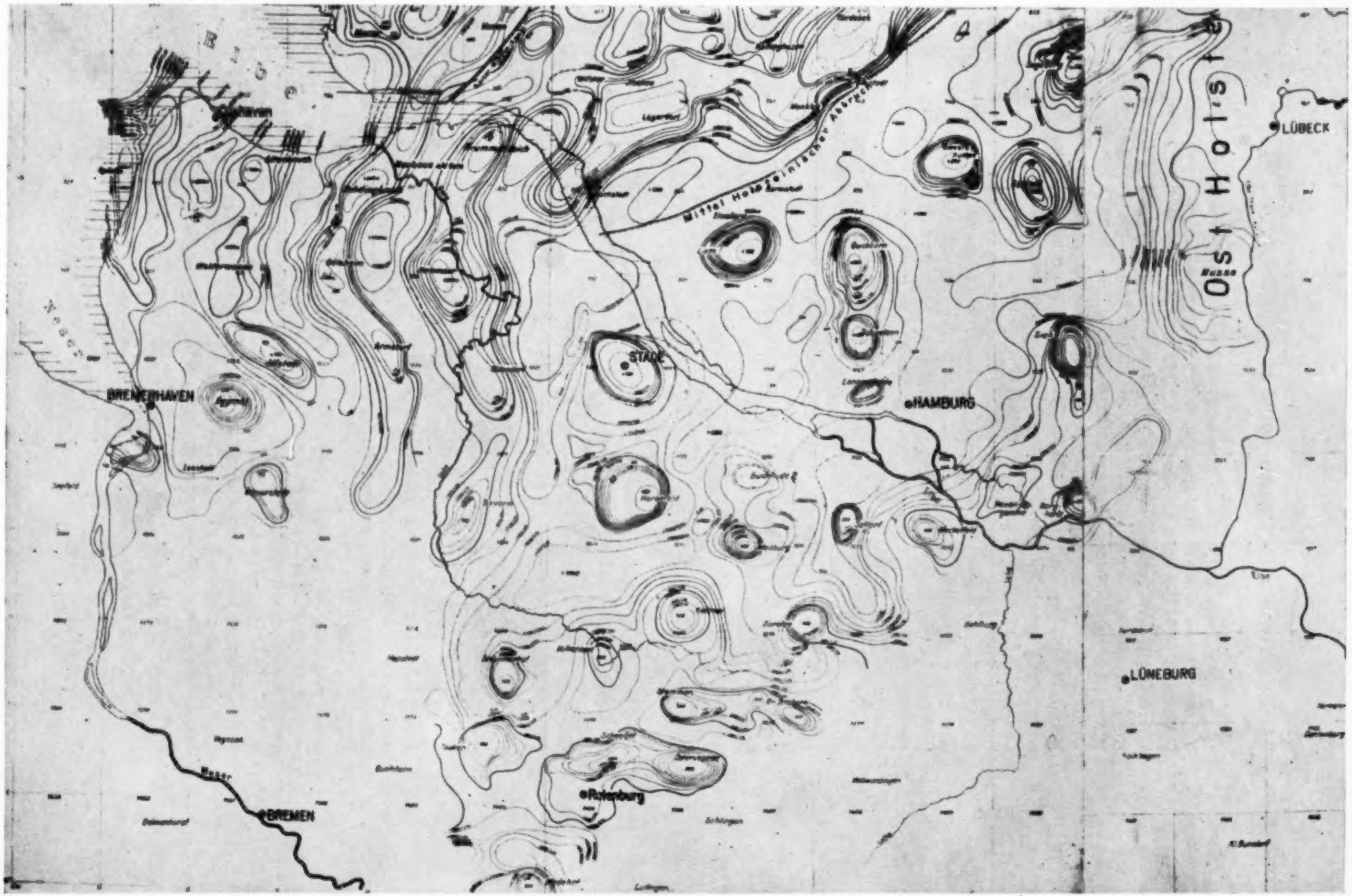


FIG. 3.—Map showing results of seismic determinations, Schleswig-Holstein, Lower Elbe. Contours represent times of equal arrival of seismic waves for 4 kilometers.

ridges consist of Rotliegendes (Lower Permian) salt and marl series. The known oil-chalk occurrence of Heide-Hemmingstedt is located on the westernmost of these ridges (Hennstedt-Heide-Meldorf). The second ridge follows Grevenhorst, Tellingstedt, Süderhastedt, Belmhusen; the third one extends from Königsbach via Oldenbuettel toward Schenefeld. Near the southern and northern ends these ridges apparently are cut off by faults.

An important structural element is furthermore (Fig. 3) represented by a northeast-striking fault zone which trends from Glueckstadt across Bad Bramstedt toward Warnau, the so-called central Holstein fault zone. Southeast of this line the Cretaceous is dropped at least 1,000 meters, and no more elongate ridges have been found, but numerous salt plugs of Rotliegendes or Zechstein were recorded by the refraction work. Some of the salt plugs represent the shallow piercement type; in other places they are deep-seated, as indicated by doming of both the Upper Cretaceous and Tertiary near Neuengamme. Farther east the Cretaceous is nearer the surface and forms the Eastern Holstein uplift.

The map is an excellent illustration of the complex structural conditions of this region and the many newly discovered structures some of which have been confirmed by drilling. Other structures are now being tested by drilling and everybody concerned with oil geology and geophysics in Germany is eagerly looking forward to a continuation of this interesting and important work.

SCIENTIFIC ILLUSTRATION
BY JOHN L. RIDGWAY[1]

REVIEW BY R. D. REED[2]
Los Angeles, California

Scientific Illustration. By John L. Ridgway. 173 pp., 23 figs., 22 pls. $7 \times 10\frac{1}{4}$ inches. Cloth. Stanford University Press (Stanford University, 1938). Price, $4.00.

In this well illustrated volume Mr. Ridgway presents facts and principles learned during a lifetime of experience as a scientific illustrator. He lists types of material—paper, pens, pencils, and many other objects, explaining when, why, and how they may be used. He outlines the methods useful for different purposes, their advantages and their limitations.

His material is divided into 58 sections. Here are the titles of every sixth section—enough to show something of the range of subjects: §6—Photographs as Illustrations; §12—Posing Specimens (Orientation); §18—Natural History Drawing; §24—Landscape or Outdoor Sketching; §30—Final Preparation of Maps; §36—Cultural Features; §42—Distinguishing Aerial Patterns for Black-and-White Maps; §48—Columnar Sections; §56—Credit for Re-Use of Published Illustrations. An appendix includes 17 tables: lengths of degrees

[1] Manuscript received, March 14, 1938.

[2] The Texas Company.

of the meridian, lengths of degrees of the parallel coördinates of curvature, the Greek alphabet, Roman numerals, mathematical signs, and several others.

The illustrations cover a wide range of subjects, add greatly to the clearness of the presentation, and, many of them, are things of beauty in themselves. A considerable proportion deal with subjects of interest to a geologist.

During the long time that is likely to elapse before the appearance of a better book on the subject, this one should be listed as required reading by all those who take the responsibility of preparing scientific illustrations for publication; also, in only less degree, by those who merely supervise their preparation.

LABORATORY EXERCISES IN PHYSICAL GEOLOGY BY WILLIAM C. PUTNAM AND ROBERT W. WEBB[1]

REVIEW BY H. W. STRALEY, III[2]
Chapel Hill, North Carolina

Laboratory Exercises in Physical Geology. By William C. Putnam and Robert W. Webb. Stanford University Press (1938). 81 pp. Price, $1.00.

This little volume appears to have solved the problem of a laboratory manual for most introductory college courses in physical geology. The eighty-one pages of explanatory and exercise material may be mastered easily in eight to fourteen class meetings of 2 hours each.

For a semester or quarter course the allocation of space is good and the exercises are carefully graded. The arrangement is satisfactory for most courses but there is sufficient latitude to permit almost any order of presentation. In courses allowing little time for laboratory work, the number of periods devoted to topographic maps may be decreased and the number of mineral species studied curtailed.

On the other hand, a few improvements could have been made.

1. On page 15, *fragmental* rocks are said to be all sedimentary. The authors are consistent in omitting pyroclastic rocks from the igneous rock table (page 24).

2. The igneous rock table (page 24) is unnecessarily complicated by the inclusion of trachyte and rhyolite (the felsites), and andesite and basalt (the basalts or traps). The beginning student finds distinctions between aphanitic rocks difficult and confusing.

3. When rocks are compressed they *may be* folded, but do not necessarily fail by bending as implied (page 38).

4. There is confusion in the use of geometrical language in the definitions of dip and strike (page 38).

The reviewer wishes to commend particularly the mention of *resistant* (not *hard*) rocks (page 61) as ridge makers in the Appalachian region. The misuse of *hard* has found its way into too many textbooks.

[1] Manuscript received, March 23, 1938.

[2] Department of Geology, University of North Carolina.

STUDIES IN SCIENTIFIC METHOD
BY DOUGLAS W. JOHNSON[1]

REVIEW BY DONALD C. BARTON[2]
Houston, Texas

"Studies in Scientific Method." A series of papers, seemingly to be in whole or in large part by Douglas W. Johnson, and to be published in the *Journal of Geomorphology*. The first discussion, "Choosing the Manner of Exposition," will appear in the next number of the *Journal*. Columbia University Press. $4.00 per year.

I wish strongly to recommend this series of discussions to all the younger members, and most of the older members, of the Association who expect to do research and to write reports on the results of the research, whether for employer, client, or publication. A really brilliant piece of work may pass unnoticed or be rated as unimportant or worthless if the presentation of the report on it is sloppy and ineffective. Professor Johnson is a master of the subject of clear and forceful presentation. Although trained under Professor Johnson, I am expecting to benefit by those discussions.

Thirty years of experience with developing young scientists have taught Professor Johnson that certain types of defects in research and presentation commonly recur in the work of young scientists and are likely to persist in greater or less degree in one's more mature productions, but that most of these defects can be eradicated entirely through conscious effort at correction and that the others can be rectified in some degree. The proposed series of discussions will cover: first, general principles which may help to guide the young scientist in presenting the results of his researches in writing; second, guiding principles for improving his oral presentation before scientific audiences; and third, and most important of all, the principles underlying different methods of pursuing scientific research and the respective advantages and disadvantages of these methods.

[1] Manuscript received, March 18, 1938.

[2] Humble Oil and Refining Company.

JOURNAL OF GEOMORPHOLOGY
EDITED BY DOUGLAS W. JOHNSON[1]

REVIEW BY DONALD C. BARTON[2]
Houston, Texas

Journal of Geomorphology. A new international journal published four times a year by Columbia University Press, New York City. $4.00 a year ($4.30 foreign).

[1] Manuscript received, March 18, 1938.

[2] Humble Oil and Refining Company.

The *Journal of Geomorphology* is a new journal which has just been established under the editorship of Douglas W. Johnson with aid from the James Furman Kemp Memorial Fund for Research and Publication in Geology. No. 1, Vol. 1 (February, 1938) has 88 pages. The main articles are: C. K. Wentworth, "Marine Bench-Forming Processes: Water-Level Weathering"; E. de Martonne, "Alignement et dissymétrie des reliefs dans la région parisienne"; S. W. Wooldridge and D. L. Linton, "The Influence of Pliocene Transgression on the Geomorphology of Southeast England"; S. B. Jones, "Geomorphology of the Hawaiian Islands," a review Twenty reviews and abstracts of books and articles are appended. The typography of the journal is pleasing. Although not within the field of interest of most of the membership of the Association, the new journal and its reviews and notes should be of interest to many of us. I have found much of interest in this number.

RECENT PUBLICATIONS

ALASKA

*"Alaska Wildcat Will Be Drilled by Three Companies," by L. P. Stockman. *Oil and Gas Jour.*, Vol. 36, No. 40 (Tulsa, February 17, 1938), p. 35; 2 figs., 1 structural dip map. Includes regional geology.

AFRICA

**Die alten Kerne* (The Ancient Coigns), Band 1, *Afrika*, Abschnitt V (1938), by E. Hennig. 142 pp., 22 figs., 2 pls. From the series *Regionale Geologie der Erde.* Akademische Verlagsgesellschaft M.B.H., Leipzig, 1938. Price, RM. 22.

CALIFORNIA

*"The Del Rey Hills Area of the Playa Del Rey Oil Field," by Loyde H. Metzner. *Summary California Oil Fields* (State Oil and Gas Supervisor, San Francisco), Vol. 21, No. 2 (1935), pp. 5–27; 3 large maps, 1 table. Published in 1937.

*"Geology and Mineral Deposits of the Western San Gabriel Mountains, Los Angeles County," by Gordon B. Oakeshott. *California Jour. Mines Geol.* (San Francisco), Vol. 33, No. 3 (July, 1937), p. 215. Geologic map.

EUROPE

**Palaeozoische Tafeln und Gebirge* (Paleozoic Plateaulands and Folded Belts), Band 2, *Northwestern Europe Caledonides*, Abschnitt II (1938), by E. B. Bailey and O. Holtedahl. 76 pp., 16 figs., 2 pls. From the series *Regionale Geologie der Erde.* Akademische Verlagsgesellschaft M.B.H., Leipzig, 1938. Price, RM. 14.

**Mittel-und Westeuropa* (Middle and Western Europe), by Hans Becker. *Ibid.*, Abschnitt III (1938). 102 pp., 31 figs.

FLORIDA

"The Molluscan Fauna of the Alum Bluff Group of Florida. Pt. IV, Pteropoda, Opisthobranchia, and Ctenobranchia," by Julia Gardner. *U. S. Geol. Survey Prof. Paper 142-F* (1938), pp. 251–435, Pls. 37–48. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.45.

GENERAL

**Palaeozoic Formations in the Light of the Pulsation Theory*, Vol. III, *Cambrovician Pulsation*. Pt. II, *Appalachian, Palaeo-Cordilleran, Pre-Andean, Himalayan and Cathaysian Geosynclines*, by A. W. Grabau. 850 pp., 58 figs., 3 pls., 1 map, 6 correlation charts. $9\frac{1}{8}\times6\frac{1}{2}$ inches. Cloth. Published by The National University of Peking. Price, Chinese, $15.00; U. S., $5.50; Great Britain and Colonies 20/—. Sales agent, Henri Vetch, The French Bookstore, Peking, China.

**Ibid.*, Vol. IV, *Ordovician Pulsation System with Notes on the Skiddavian (Canadian) System* (in press). $9\frac{1}{8}\times6\frac{1}{2}$ inches. Published by Henri Vetch, Peking. Price, Chinese, $15.00; U. S., $5.50; Great Britain and Colonies, 20/—.

**Scientific Illustration*, by John L. Ridgway. 173 pp., 23 figs., 22 pls. $7\times10\frac{1}{4}$ inches. Cloth. Stanford University Press, Stanford University, California (1938). Price, $4.00.

"Properties of Typical Crude Oils from Fields of the Eastern Hemisphere," by A. J. Kraemer and E. C. Lane. *U. S. Bur. Mines Bull. 401* (1938). 169 pp., 8 figs. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.20. Includes comments, tabulated data, and individual analyses of 142 samples of crude petroleum obtained from Albania, Roumania, Yugoslavia, Greece, Russia, Iran, Iraq, India, Japan, East Indies, New Zealand, Algeria, Egypt, and Angola.

Rotary Drilling Handbook, Second edition, by J. E. Brantly. 350 pp.; 99 pp., formulas and tables. $7\frac{1}{2}\times5\frac{1}{4}$ inches. Morocco. Palmer Publications, Los Angeles (1938). Price, $3.50; foreign, $4.00.

*"Acidizing Core Samples," by L. C. Chamberlin, Jr. *Oil Weekly* (Houston), Vol. 88, No. 12 (February 28, 1938), pp. 20–34; 9 figs.

"Relation of Salinity to the Calcium Carbonate Content of Marine Sediments," by P. D. Trask. *U. S. Geol. Survey Prof. Paper 186-N* (1938), pp. 273–99, Pl. 71, Figs. 12–19, Tables 1–7. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.50.

"Bibliography of North American Geology for 1935 and 1936," by E. M. Thom. *U. S. Geol. Survey Bull. 892* (1938), 504 pp. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.50.

ILLINOIS

"Structure of Herrin (No. 6) Coal Bed in Central and Southern Jefferson, Southeastern Jefferson, Southeastern Washington, Franklin, Williamson, Jackson, and Eastern Perry Counties, Illinois," by G. H. Cady. With "Notes on Oil and Gas Possibilities," by Alfred H. Bell. *Illinois State Geol. Survey Division Cir. 24* (Urbana, 1938). Free.

"Oil and Gas Map of Illinois," by Alfred H. Bell and George V. Cohee. *State Geol. Survey* (Urbana, 1938). Scale, 1:500,000. Price, $0.35. Free to Illinois residents and to libraries, except for mailing charge of 10 cents, until June 1, 1938.

KANSAS

*"The Trapp Pool of Kansas," by B. A. Lilienborg. *Petroleum Investor* (Tulsa), Vol. 2, No. 2 (February, 1938), p. 14. 1 map.

*"Geology of Rawlins and Decatur Counties with Special Reference to Water Resources," by Maxim K. Elias. *Bull. Univ. Kansas* (Lawrence), Vol. 38, No. 13 (July 1, 1937), *Min. Resources Cir. 7*. 25 pp. 2 figs., 2 maps.

*"Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas," by N. Wood Bass. *State Geol. Survey Kansas Bull. 23* (1936, printed 1937). 135 pp., 10 figs., 21 pls., 1 map in pocket.

NEW MEXICO

*"Carbon dioxide in New Mexico," by E. H. Wells and A. Andreas. *New Mexico School Mines Gold Pan, Supp. 1* (Socorro, January 31, 1938).

OHIO

*"Middle Devonian Corals of Ohio," by Grace Anne Stewart. *Geol. Soc. America Spec. Paper 8* (February, 1938). 120 pp., 2 figs., 20 pls.

ROCKY MOUNTAIN REGION

**Résumé Rocky Mountain Oil and Gas Operations for 1937*. Published by Petroleum Information, Inc., Denver, Colorado (February, 1938). 145 pp., maps, tables. Tenth volume of a series of annual publications presenting facts of general interest about oil and gas developments.

RUSSIA

*"Steinsalzlagerstätten, Solquellen und Salzseen" (Salt Deposits, Salt Springs, and Salt Lakes), by N. Polutoff. Reprint from "Die Lagerstätten der nutzbaren Mineralien und Gesteine," *Fulda, Steinsalz und Kalisalze*, Band III, Teil 2, pp. 169–202, Figs. 85–87. Published by Ferdinand Enke, Stuttgart, Germany.

TEXAS

"Stratigraphic, Structural, and Paleontologic Studies of the Pennsylvanian and Permian Rocks in North-Central Texas," by Wallace Lee, C. P. Nickell, Lloyd G. Henbest, and James S. Williams. *Univ. Texas Bull. 3801* (Austin, March, 1938). 260 pp., 9 figs., 11 pls. Paper. Price, $1.50.

"The Geology of Leon County, Texas," by H. B. Stenzel. *Univ. Texas Bull. 3818* (Austin, March, 1938). 170 pp., 20 figs., 3 pls. Geologic map in colors; scale, 1:96,000. Paper bound. Price, $1.00.

Generalized maps showing distribution at surface and underground so far as known of Upper Cambrian, Lower, Middle, and Upper Ordovician, Silurian, and Devonian formations in Texas, by E. H. Sellards. White prints. Scale, 1 inch: 40 miles. Price, $0.50 per map. These maps are advance prints from *The Geology of Texas, Vol. IV, Petroleum Resources*.

*"Deep Sand Production at K. M. A.," by John W. Merritt. *Petroleum Investor* (Tulsa), Vol. 2, No. 2 (February, 1938), p. 10; 1 map.

WASHINGTON

*"Summary of Late-Cenozoic Geology of Southeastern Washington," by Richard Foster Flint. *Amer. Jour. Sci.* (New Haven, Connecticut), Ser. 5, Vol. 35, No. 207 (March, 1938), pp. 223–30.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 12, No. 2 (March, 1938).

"A Microfauna from the Vaqueros Formation, Lower Miocene, Simi Valley, Ventura, California," by J. A. Cushman and L. W. LeRoy

"Miocene and Pliocene Ostracoda of the Genus *Cytheridea* from Florida," by Morton B. Stephenson

"Aturias from the Tertiary of Mexico," by A. K. Miller and W. M. Furnish

"The Conodont Genus *Icriodus* and Its Stratigraphic Distribution," by E. B. Branson and M. G. Mehl

"*Triplalepidina veracruziana*, a New Genus and Species of Orbitoidal Foraminifera from the Eocene of Mexico," by Thomas Wayland Vaughan and W. Storrs Cole

"Some Foraminifera of the Family Textulariidae from the Eocene of Cuba," by C. G. Lalicker and P. J. Bermúdez

"A New Family of Charophyta from the Lower Cretaceous of Texas," by Raymond E. Peck

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1935," by Hans E. Thalmann

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THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Memorial

JOHN MALCOLM MUIR
(1885–1938)

On January 19, 1938, John Malcolm Muir died in Sydney, N.S.W., Australia, while in charge of field work for the Island Exploration Company, Pty. Ltd. of Melbourne. He had been in New Guinea for a year as chief geologist for the company. After a brief business journey to Melbourne, he was returning to Papua when suddenly stricken with heart failure in Sydney. Burial was in Cypress Lawn Cemetery, San Francisco, California, February 23. Mr. Muir is survived by his wife and son, Alan, of Fort Worth, Texas, and a daughter, Mrs. W. B. Petersen, of San Francisco.

To every geologist, driller, and lease foreman who ever worked in the Tampico Region of Mexico, he was Johnny Muir, and was accorded a preëminent place in respect and affection by all of them. His ability was also recognized by his appointment to write the volume issued in 1936 by the Association, entitled *Geology of the Tampico Region, Mexico*. It is therefore particularly appropriate to review the outstanding achievements of one of the pioneer specialists both in petroleum geology and in coördination of geology and drilling.

He was born in Scotland, July 18, 1885, and graduated with the degree of Economic Geologist in 1907 from Herriott-Watt College at Edinburgh. He was appointed to the Geological Survey of Great Britain, on which he worked until 1912. In addition to the class-room instruction and field work in geology, he studied, largely as an avocation, machine-shop practice and photography, in which he continued to maintain a lively interest, so that he understood construction and maintenance of steam and gas engines, which is of great significance in explaining the reception he received among drillers and those who pioneered in Mexico with automobiles and motor boats. His photographs of interesting events in Mexican oil development were also an open sesame to many who wished remembrances of those events.

In 1912 he came to Mexico, when the Panuco field drilling had barely resulted in production, and in addition to field work in undrilled areas, notably in Southern Tamaulipas, began the systematic examination of well cuttings and collection of drilling information. At that time, official logs were fragmentary, and the formations drilled were difficult to zone on any basis. He used as criteria, color, hardness, texture, and drilling speed, making allowance as regards the last mentioned for the mechanical equipment and the idiosyncracies of the drillers, and in a few years was recognized as *the* authority. His laboratory equipment was a hand lens and an acid bottle.

To show his uncanny accuracy, one case may be reported. He was given some cuttings with no label. His comment was "150 feet above the top of the white lime horizon of the Panuco field, but not in this field or in Topila, because somewhat more indurated." Subsequent drilling in the well, a wildcat approximately 35 miles from the Panuco field, proved his identification correct.

Early in his field work in Mexico, he became interested in archeology,

and not only did he find new localities, but he modestly arranged for contacts to enable others to carry on investigations.

Muir's interest did not cease with the correlation of drilling wells, but he collected production data, and when invasion of water in the Panuco field began, he contributed to the development of "stripping," and here again his prestige with the production men, usually ex-drillers, facilitated the reception of his recommendations.

His services in Mexico of this period extended from 1912 to 1926, and although he was successively field geologist, production geologist, and acting chief geologist for the Corona (Dutch Shell), his advice and coöperation were

JOHN MALCOLM MUIR

extended to all the geologists and he found time to perform countless courtesies to many visitors to the region, among whom are probably all of the Association members reading these paragraphs who have at any time visited the Tampico region.

He joined the Institution of Petroleum Technologists in 1920 and the American Association of Petroleum Geologists in 1924.

In 1926, he accepted an offer to join the Turkish Petroleum Company in Mesopotamia, where an epoch of drilling into reservoirs similar to those of Mexico was beginning, but at the end of 2 years, there was an offer to join with some of his American friends formerly operating in Mexico, and he came to the United States, with office in Dallas. In 1929 he joined the Southern Crude Purchasing Company as liaison geologist in a geophysical campaign in South Texas, which was completed in 1931.

For some years, he had been collecting material for a paper on the production history of Mexico. He discussed the project with several friends, and decided to expand it to include the geology of the Tampico region. The project was to collate all of the published literature, and he began the careful scrutiny of all of the correlation of the different sections made by the geologists who had worked in that part of Mexico. A grant was received through the Association, but this was only a small part of the expense involved, and he contributed the balance personally because he felt the work was a tribute to the petroleum industry and would be a reminder of an epochal oil district. There is nothing of the pageantry of those days in the book itself—he considered it should be precise and documented. Only to those privileged to have heard his verbal comments in Boswellian vein on the sources of his material and on the incidents of fossil discoveries, of well completions, of production history, can the book and the author bring the richest memories.

In this brief tribute it is my hope to share the spirit of these memories with all the Association. Johnny Muir leaves with his co-workers the inspiration of a geologist whose avocations happily broadened his geological opportunities, whose perspicuity, sharpened by careful early field work, solved his geological problems, and whose modesty and coöperation made effective his conclusions among his co-workers, whether geologists or drillers. We think of him as among the first great production geologists.

PAUL WEAVER

HOUSTON, TEXAS
March 1, 1938

ARTHUR W. DUSTON
(1886–1938)

Arthur W. Duston, consulting geologist and president of the Commonwealth Royalties Company, Tulsa, Oklahoma, died February 2, 1938, after a brief illness due to high blood pressure and hardening of the arteries. He is survived by his widow, and two sons, Dean, age 15, and Glenn, age 10.

Duston was born in Washington, Kansas, September 5, 1886. He graduated from Valparaiso University, Valparaiso, Indiana, in 1910, with a Bachelor of Science degree. He received a Bachelor of Arts degree in 1914 from the University of Kansas.

Duston served as reconnaissance geologist in 1912 for the Kansas State Geological Survey. In 1914–1915 he was division chief for the Basin Oil Company with headquarters at Alberta, Canada, and during 1916–1917 he did geological work for the Empire Gas and Fuel Company on the Gulf coast. He enlisted in the Army in 1917. He was commissioned a First Lieutenant and ordered to France attached to the General Headquarters Staff performing geological work in connection with army operations.

He received his discharge from the Army in 1919 and became division chief for the Emerald Oil Company. In 1920 he joined the geological staff of the Pierce Oil Corporation, and was stationed in Okmulgee, Oklahoma, as division chief. In 1923 he became chief geologist and head of the land department for the Independent Oil Company. He held this position until his resignation in 1927 when he opened his offices in Tulsa as a consulting petroleum geologist and engineer. At the time of death he was president of the Commonwealth Royalties Company.

Duston was a thorough and capable geologist and left many friends among the geologists and the oil fraternity. His quiet sense of humor, sincerity, and integrity endeared him to his host of friends and the loss of him will be keenly felt by these friends and his business associates. He has been credited with the discovery of the Mason pool in Loving County, Texas, as well as discoveries in the Seminole area in Oklahoma.

Mr. Duston was a member of the Acacia Fraternity, Masons, Shrine Akdar Temple, Tulsa, Tulsa Geological Society, American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, Sigma Gamma Epsilon, and past-president of the Mid-Continent Royalty Owners Association.

LOUIS ROARK

TULSA, OKLAHOMA
March 8, 1938

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WILLARD F. BAILEY, Skelly Oil Company, has been transferred from Pampa, Texas, to Shreveport, Louisiana, to take charge of the geological department of the north Louisiana-Arkansas division.

WILLIAM F. JENKS may now be addressed in care of Cerro de Pasco Copper Corporation, Cerro de Pasco, Peru, South America.

WILLIAM C. KNEALE, formerly district geologist for The Texas Company at Mattoon, Illinois, has been named superintendent for the company in the Illinois-Indiana district with headquarters at Mount Vernon. He is succeeded as district geologist by B. M. MILLER.

At the meeting of the American Association for the Advancement of Science at Indianapolis the Section on Geology and Geography held its sessions December 31 and January 1. Some of the papers of interest to geologists are as follows: "St. Peter Sandstone in Kentucky," by WILLARD JILLSON; "Oil Reservoirs," by F. B. PLUMMER. A group of papers was presented as a symposium on "Oil in the Pennsylvanian of the Eastern Interior Basin"; HAROLD R. WANLESS reviewed Illinois; CLYDE A. MALOTT reviewed Indiana; and L. C. GLENN reviewed Kentucky. Special aspects of the stratigraphy and structure of the basin were presented in papers by L. M. WELLER and W. A. NEWTON, ALFRED H. BELL and GEORGE V. COHEE, and G. E. EKBLAW. Current oil development in the region was discussed by C. J. HARES, and micropaleontological data of the basin were presented by C. O. DUNBAR, L. G. HENBEST, and J. M. SCHOPF. The Eastern Interior and Michigan basins were compared by R. A. SMITH.

L. E. WORKMAN, Illinois Geological Survey, Urbana, recently read a paper, "Subsurface Stratigraphy of Cypress to Ste. Genevieve Formations in the Illinois Basin," at a meeting of mid-western geologists studying development of the Illinois Basin area held in Mattoon. Formal discussions of the paper were presented by J. R. MCGEHEE, Centralia, CARL B. ANDERSON, Mattoon, and ROBERT G. KURTZ, Marshall.

H. W. STRALEY, III, University of North Carolina, Chapel Hill, recently delivered an address before the seismic and magnetic divisions of the U. S. Coast and Geodetic Survey and the geophysical division of the U. S. Geological Survey on the subject, "Geomagnetic Work in the Southern Appalachians and on the Coastal Plain South of the Potomac River."

FREDERICK J. SMITH, Shell Petroleum Corporation, has been transferred from Hobbs, New Mexico, to Wink, Texas.

RAY A. HANCOCK has resigned his position with the Birch Oil Company and has accepted a position with the Lane-Wells Company of California at Long Beach.

Guy E. Green, Wellington Oil Company of Delaware, San Antonio, spoke before the South Texas Geological Society, February 18, on "Seven Sisters Field of Duval County."

"Stratigraphy and Lithology of the Pre-Gulf Subsurface Strata in South Arkansas," is the title of a paper read by Warren B. Weeks, Phillips Petroleum Company, before the Shreveport Geological Society.

Lloyd I. Yeager, formerly with the Cities Service Oil Company, is now engaged in consulting work in Wichita, Kansas.

James H. Gardner, Tulsa, recently addressed a meeting of the Mid-Continent Royalty Owners Association on the geology of the new producing area near Stillwater, Oklahoma.

The first of a series of lectures to be made by geologists to the geology students of Tulane University, New Orleans, was given by J. Brian Eby, Houston.

Recent grants made by the Geological Society of America in furtherance of research are as follows.

$10,300 to Francis P. Shepard, University of Illinois, in coöperation with the Scripps Institution of the University of California at La Jolla, for the investigation of the physiography, current dynamics and sedimentation in selected areas of the sea floor off the California coast.

$1,000 to W. F. Prouty, Chapel Hill, North Carolina, for magnetometer study of the origin of the "Carolina bays" of the Atlantic Coastal Plain suspected by some geologists to have been due to a shower of meteors.

$254 to John T. Lonsdale, Ames, Iowa, for a petrographic study of igneous rocks from the Terlingua district, Texas.

$572 to George M. Schwartz, Minneapolis, Minnesota, and A. E. Sandberg, Cincinnati, Ohio, for analyses of several phases of three Keweenawan sills closely related to the Duluth gabbro.

$1,000 to Arthur C. Veatch, New York City, for continuation of his investigation, in coöperation with the United States Coast and Geodetic Survey, of submarine topography off the Atlantic coast, beyond the 1,000-fathom line.

$6,300 to Alfred C. Lane, Cambridge, Massachusetts, for continuing determination of ages of rock specimens by the helium method.

$750 to G. Marshall Kay, New York City, for a study of the structure of northeastern Ontario with a view to correlating the peneplain of central Ontario and revising paleographic maps.

$500 to Frank M. Swartz, State College, Pennsylvania, for study of ostracoda from Lower Devonian-Upper Silurian beds, chiefly from southeastern New York and New Jersey.

$405 to Raymond E. Peck, Columbia, Missouri, covering collecting and studying oögonia and ostracoda from late Cretaceous and early Tertiary beds of Wyoming, eastern Idaho, and Montana.

$1,200 to Robert T. Hill, Dallas, Texas, to continue investigation of the history of geological exploration of the southwest.

$2,000 to Frank F. Grout, Minneapolis, Minnesota, contribution to the support of the University of Minnesota Laboratory for Rock Analysis, in the service of petrologic science.

$300 to WILLIAM C. PUTNAM, Los Angeles, California, for completion of physiographic study of the Ventura region, California.

$1,200 to ROGER REVELLE, Scripps Institution of Oceanography, of the University of California at La Jolla, California, for systematic study of sediments from the floor of the Pacific.

$100 to HORACE R. BLANK, Waco, Texas, for analyses supporting investigation of the occurrence and nature of an unusual feldspathoid dike rock encountered in one of the many tunnels in the Manhattan schist under New York City.

$340 to NELSON H. DARTON, Washington, D. C., to continue an investigation of overlap relations of Tertiary and Cretaceous formations in eastern Maryland and Virginia.

KARL SCHILLING, Shell Petroleum Corporation, has been transferred from Saginaw, Michigan, to Shreveport, Louisiana.

C. I. ALEXANDER, Magnolia Petroleum Company, Houston, spoke before the Houston Geological Society, February 24, on the subject, "A North and South Cross Section of the Louisiana Gulf Coast."

RALPH J. SCHILTHUIS, Humble Oil and Refining Company, Houston, spoke before the Dallas Geological Society, March 7, on the subject, "Connate Water in Oil and Gas Sands." He spoke before the Fort Worth Geological Society, March 8, on the same subject.

RICHARD HUGHES, formerly chief geologist and head of the land department for the Burke-Greis Oil Company, Tulsa, resigned March 1, to become engaged in independent practice.

The State of Arizona has employed OSCAR HATCHER, consulting geologist, Ada, Oklahoma, to make a geologial survey of Arizona.

CEVAT E. TASMAN, Ankara, Turkey, recently spent 40 days in Europe making personal contact with the drilling-equipment companies in Roumania, Hungary, Austria, Germany, and England.

L. G. WEEKS has been transferred as chief geologist of the Standard Oil Company of Argentina, at Salta, to New York where his address will be Room 1514, 30 Rockefeller Plaza.

J. WHITNEY LEWIS has changed his address from Santo Domingo to Trujillo City, Dominican Republic.

WENDELL B. GEALY may be addressed in care of the Gulf Oil Corporation, Box 1166, Pittsburgh, Pennsylvania.

WILLIAM D. CORTRIGHT, formerly with the Associated Oil Company at Oil Center, California, is now with the Tide Water Associated Oil Company at Oildale, California.

EARL A. TRAGER presented an illustrated lecture on the geology in the National Parks before the Tulsa Geological Society, March 23.

PHILLIP ANDREWS has changed his address from Boulder, Colorado, to Apartado 246, Caracas, Venezuela, S. A.

THOMAS F. GRIMSDALE may be addressed to Cia. Guatemalteca de Petroleo Shell, Apartado 379, Guatemala City, Central America.

ROBERT S. BREITENSTEIN may be addressed at 2501 Albion Street, Denver, Colorado, between April 1 and July 1. During this time he will be in the United States on vacation.

DONUIL HILLIS, formerly with the Chanslor Canfield Midway Company, Fellows, California, has resigned to accept a position as geologist for the California Lands Incorporated, Burlingame, California.

C. MAYNARD BOOS, geologist and geophysicist, is in charge of the new district office of the Independent Prospecting Company at 21 Demaree Building, 16th and Broadway, Mattoon, Illinois. This company is a subsidiary of the Independent Exploration Company.

BENNETT FRANK BUIE, with Amiranian Oil Company on its extensive surveys in the Iran province in 1937, has been transferred to Afghanistan where he will work in association with ERNEST F. FOX for Inland Exploration Company.

CHESTER R. THOMAS and O. C. OLSON left New York on March 15 on the S. S. *Excambion* for Karachi, India, from which place they will go into southern Iran for geological work with the Amiranian Oil Company. Their post-office address will be 10 Khiaban Nosrat, Teheran, Iran.

W. A. MALEY, Humble Oil and Refining Company, was elected president of the South Texas Geological Society at a meeting recently held in San Antonio. C. C. MILLER, The Texas Company, was elected secretary-treasurer; W. W. MCDONALD, Arkansas Natural Gas Company, was elected vice-president; DON BARNETT, Union Producing Company, was elected to the executive committee.

LEON R. VESLEY and C. J. C. HARVEY, Amerada Petroleum Corporation, have been transferred from Shawnee, Oklahoma, to Houston, Texas. W. G. MEYER, geologist in the Houston office, has been transferred to Shawnee.

KENNETH R. PARSONS and GORDON L. POSTLE left New York on March 5 for Kabul, Afghanistan, where they will be doing geological work for the Inland Exploration Company. HOWARD M. KIRK, Inland Exploration Company, has lately been surveying the southern Afghan desert regions on camel back. HENRY C. REA, with the same company, has been assigned to work in the promising area not far from Kandahar in southeastern Afghanistan.

A group of parties headed by FREDERICK G. CLAPP, LESTER S. THOMPSON, HUBERT G. SCHENCK, and HENRY HOTCHKISS, whose offices are at Zahidan, Province of Makran, are engaged in surveying the vast basin areas of southeastern Iran. CLAPP recently drove across from the fields of Inland Exploration Company in Afghanistan to supervise this work. THOMPSON is in local charge for the Amiranian Oil Company in this part of Iran. SCHENCK is conducting paleontological researches through the great thicknesses of Lower Tertiary and Upper Cretaceous sediments in that part of the country. HOTCHKISS, until recently assisted by H. A. AFSHAR, is making detailed surveys on some of the attractive structures. E. GARDNER CLAPP is employed on some of the technical and administrative phases of the surveys, at times in Zahidan.

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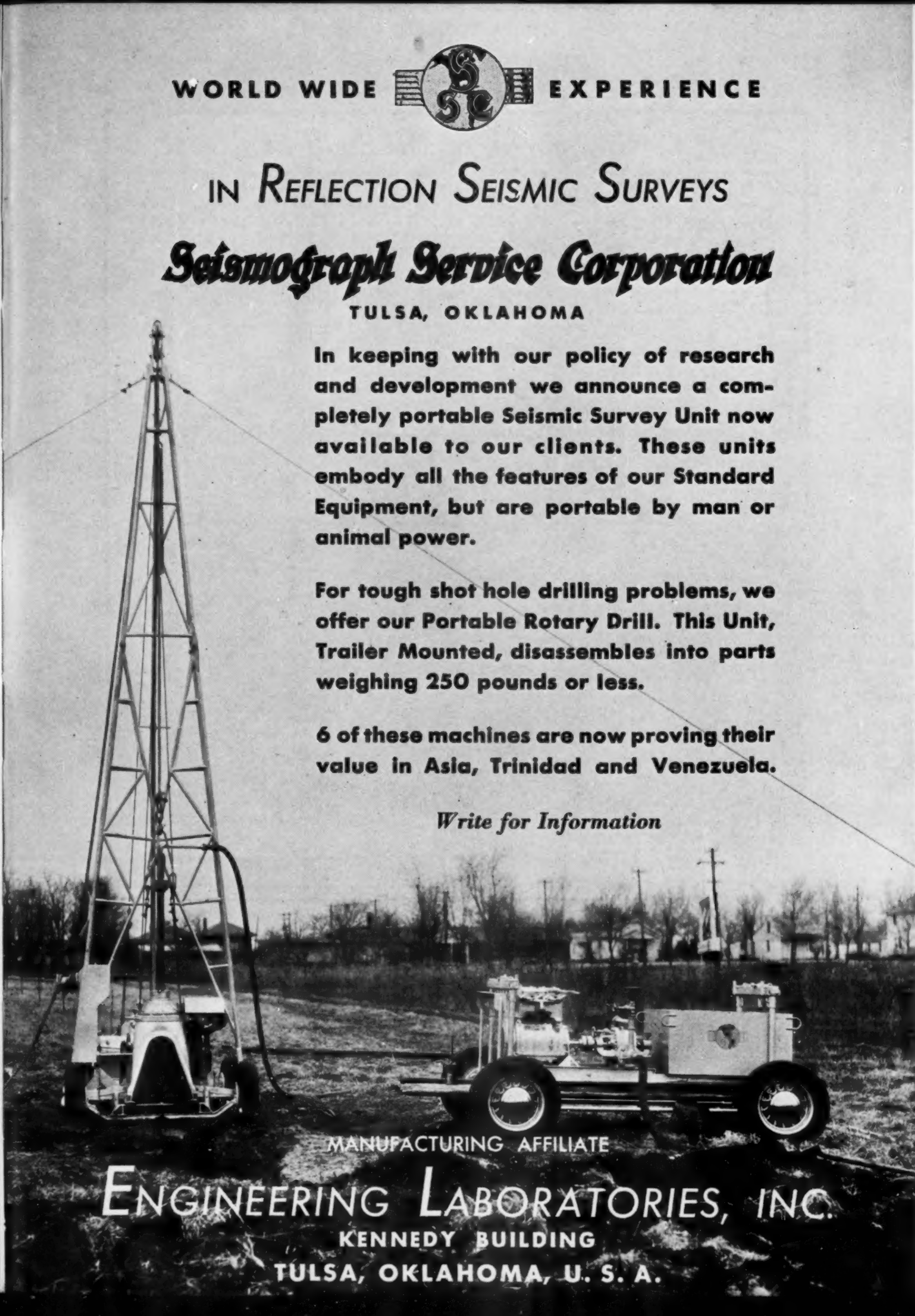
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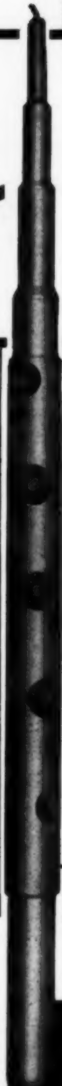

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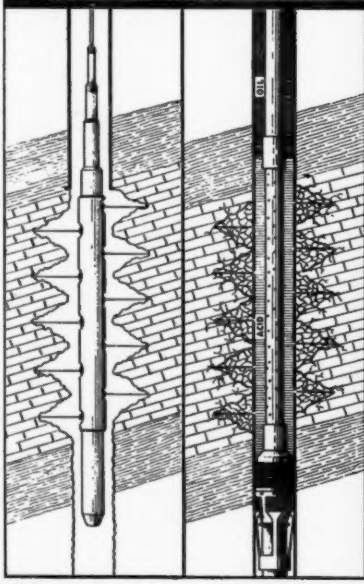

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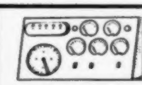

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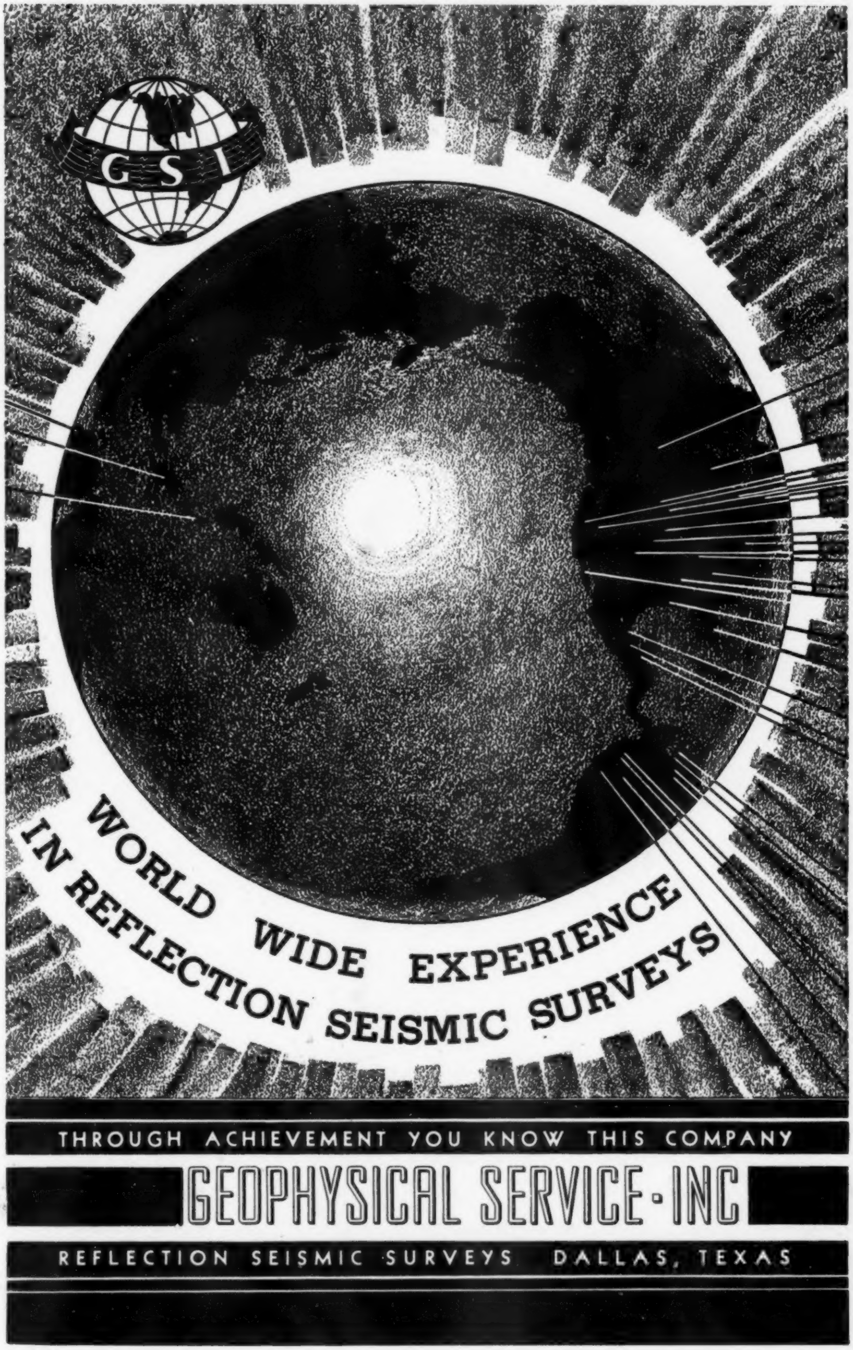
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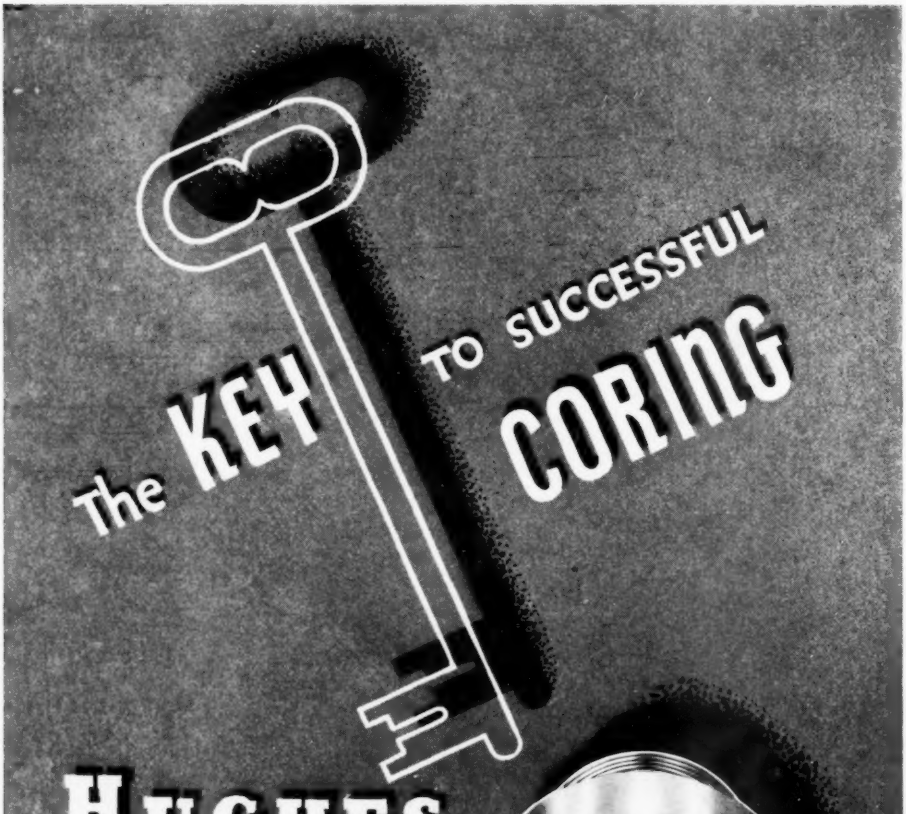
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